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ORIGINAL ARTICLES.

I.—Notes on new or imperfectly known Chalk Polyzoa.

By R. M. Brydone, F.G.S.

(*Continued from the March Number, p. 100.*)

PLATE X.

Membranipora missilis, sp. nov. (Pl. X, Figs. 1, 2.)

Zoarium unilaminate, adherent.

Zoœcia strongly pyriporiform, very small, length about ·4 mm.; areas broadly speaking elliptical but with a strong tendency to have the upper end flattened rather askew to the central line, average length ·18 mm., breadth ·11 mm.; the side walls of the area bear about a dozen tubercles so small that their existence is only just recognizable under a 3 in. objective; a 1 in. objective shows them to be perforated; below the area there is typically (after the early stages) a small perforated boss placed centrally on the front wall, but when the front wall has to accommodate an oœcium the boss splits into two, often very massive, one on either side of the oœcium.

Oœcia very large in proportion, globular but tending to end in a definite but blunt point like an artillery shell; free edge narrowly and deeply concave.

Avicularia vicarious, fairly numerous, consisting of a shallow and wide pan with a small rounded aperture at the lower end; over the lower part of this aperture the side walls are sharply pinched in.

This species appears in the zone of *Marsupites* in Hants and Sussex, where it is rare, and also occurs very sparingly in the zones of *Offaster pilula* and *Actinocamax quadratus*. It has a superficial resemblance to *M. coralliformis*, Bryd.,[1] which is curiously strong considering that their avicularia are the only point of resemblance in detail.

Membranipora Fannia,[2] sp. nov. (Pl. X, Figs. 3, 4.)

Zoarium unilaminate, adherent.

Zoœcia pyriporiform, of fair size, length about ·5 mm.; areas corresponding in shape to those of *M. missilis* (*supra*), average length ·29 mm., breadth ·2 mm., surrounded by a flat rim which is narrow

[1] Geol. Mag., 1910, p. 259, Pl. XXI, Figs. 4, 5.

[2] The difficulty of finding any Latin word at once distinctive and appropriate as a specific name in a genus such as *Membranipora*, with its hundreds of species already described, is so acute that I have followed the example set by D'Orbigny with *Eschara* of using classical names. He got as far as E, so I have begun with F.

and sharply marked in the upper part but widens towards the lower end and almost dies away; on this rim are four pairs of tubercles, of which the two highest are prominent and perforated, the third is distinctly less prominent and probably perforated, and the lowest very faint and probably not perforated; just above the upper corners of the area there are sometimes indications of a pair of tiny pores or perforated tubercles; the external front wall bears a small central perforated boss, which may be shifted to one side when the front wall has to accommodate an oœcium, but generally seems to disappear.

Oœcia globular, sturdy, with a concave free edge lying well back from the area.

Avicularia, apart from the possibilities of the central boss, do not occur.

This species is fairly well distributed, though sparingly, in the zone (restricted) of *A. quadratus*. It has obviously many points of general affinity to *M. missilis*, but no close relationship can be alleged in view of the following species.

Membranipora cupolata, sp. nov. (Pl. X, Figs. 5, 6.)

Zoarium unilaminate, adherent.

Zoœcia pyriporiform, small, length about ·4 to ·45 mm.; areas slightly elliptical, but almost, sometimes quite, round with an average diameter of ·16 mm.; round their upper end there are about five small perforated tubercles; after the early stages a perforated boss appears on the front wall and rapidly assumes very large proportions; when the front wall has to accommodate an oœcium, the boss splits into what appear under a 3 in. objective to be two tubes generally inclined forward and obliquely truncated in the horizontal plane so as to give an elongated section, but under a 1 in. objective prove to be tiny avicularia of the same general type as those of *M. missilis*, highly exsert, and directed indiscriminately backwards or forwards.

Oœcia very striking, narrow, and very long, and ending in a short spike like a dome and cupola; the spike generally projects over the area of the succeeding zoœcium and so is very plainly visible.

No vicarious avicularia observed.

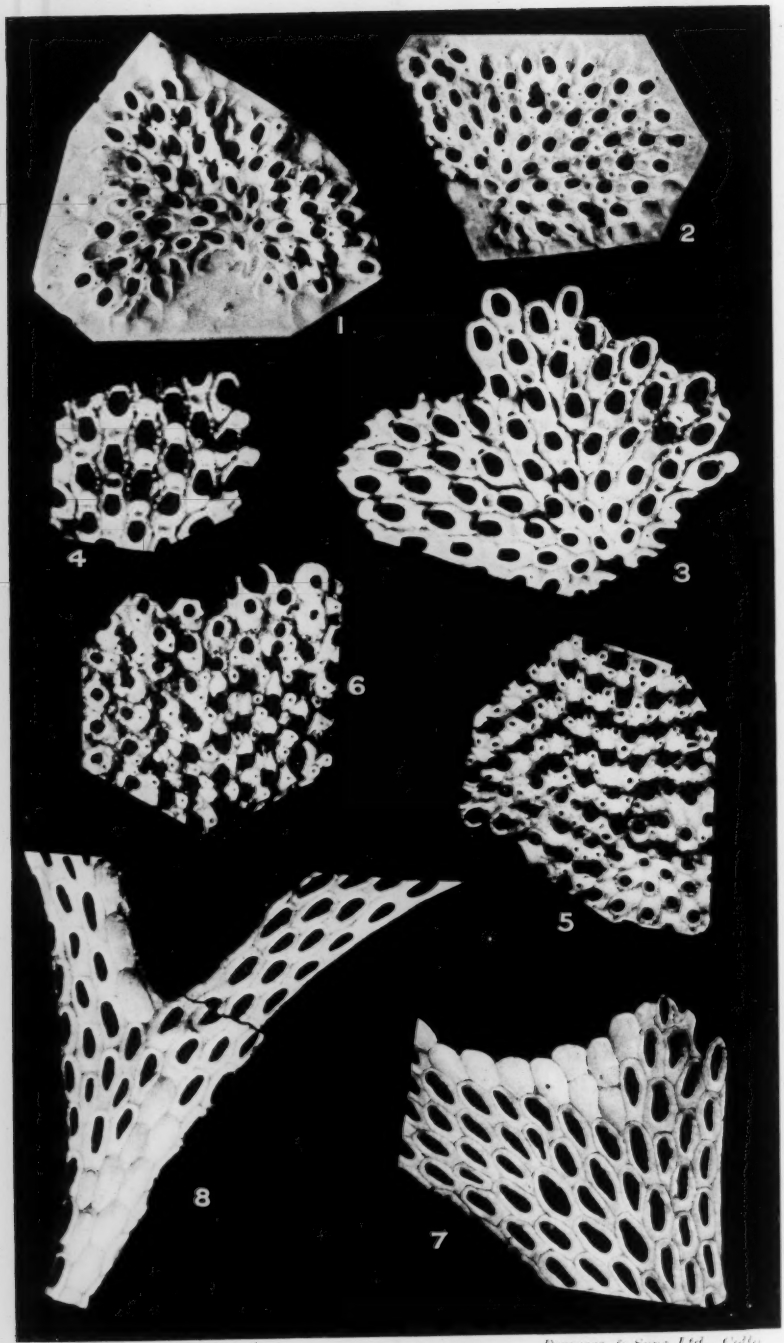
This species, which is very compact and thick in appearance, is fairly abundant at Trimingham and occurs also in the Weybourne Chalk. Its surface is so uneven that photographs hardly do it justice. Its affinity with *M. missilis* is obviously very close apart from the avicularia.

Membranipora vectensis, sp. nov. (Pl. X, Figs. 7, 8.)

Zoarium 'bilaminate', branching, branches generally broad; the central lamina is very thick in proportion to the zoœcia, and occupies about three-fifths of the total thickness of the zoarium.

Zoœcia lengthily hexagonal, average length ·55 to ·6 mm., side walls decidedly wide; areas shallow, long and narrow, with a strong tendency to pointed ends especially at the lower ends, and often sealed by a calcareous lid; they generally stop short some way from the lower end of the zoœcia, which then have a piriform appearance.

No oœcia or avicularia have been observed.



R. M. Brydone phot. Fewtrell & Sons Ltd., Colln.

Chalk Polyzoa.

This species is only known to me from the Isle of Wight, where it occurs all over the island sparingly in the zone of *Holaster planus* and freely in the Chalk between the 'grey marl' and the 'black marl'. It is very near akin to *Biflustra lacrymopora*, D'Orb.[1]; but the thick central lamina, the wide and clumsy-looking side walls and narrow area, and the total absence, as far as my experience goes, of oœcia seem full warrant for a specific separation which the very restricted horizontal and vertical range, and the great rarity of Biflustrine forms in our Chalk, would tempt one to make on slenderer grounds.

EXPLANATION OF PLATE X.

(All figures × 12 diams.)

FIG.

1. *Membranipora missilis*. Zone of *Marsupites*. Well, Hants.
2. *M. missilis*. Zone of *Marsupites*. Brighton.
3. *M. Fannia*. Zone of *A. quadratus*. Shawford, Hants.
4. *M. Fannia*. Part of the same specimen in a different light.
5, 6. *M. cupolata*. Trimingham.
7, 8. *M. vectensis*. Zone of *Holaster planus*. Culver Cliff, Isle of Wight.

(*To be continued.*)

II.—The Structure and Later Geological History of New Zealand.

By C. A. Cotton, D.Sc., F.G.S., Victoria University College, Wellington, N.Z.

The Mesozoic Orogenic Movements.

As is well known, the skeleton or oldermass[2] of New Zealand is largely composed of a mass of deformed sedimentary rocks, the precise ages of the members of which are in doubt but do not affect the problem under consideration. The most profound deformation of this vast sedimentary group took place in late Jurassic or early Cretaceous times during what may be termed the "Mesozoic orogenic period", when probably a great mountain range came into existence.

It was the opinion of Hutton[3] that the mountain range which resulted from the Mesozoic folding still survives in the present-day mountains of New Zealand; but this view, though accepted by Suess,[4] is not specifically maintained by any modern New Zealand geologist. The contrary opinion has, however, rarely been expressed.[5]

[1] Pal. Crét. Franç., v, p. 274, pl. 695, figs. 1–3.

[2] The writer employs the convenient terms 'oldermass' and 'covering strata' or simply 'cover' in the sense in which similar terms were introduced by W. M. Davis ("Relation of Geography to Geology," Bull. Geol. Soc. Am., vol. xxiii, pp. 93–124, 1912). 'Oldermass' means a mass of rocks, generally of complex structure and of various ages, which have been planed down by erosion and which have been covered, during a later period of submergence, by a series of 'covering strata'.

[3] F. W. Hutton, *The Geology of Otago*, Dunedin, 1875, p. 10; see also "On the Geology of the New Zealand Alps", Proc. Roy. Soc. Tas., 1886.

[4] E. Suess, *The Face of the Earth*, vol. ii, p. 148, Oxford, 1906.

[5] But see P. G. Morgan, "The Geology of the Mikonui Subdivision, North Westland," N.Z. Geol. Surv., Bull. 6, 1908, p. 43; and also R. Speight, "The Mount Arrowsmith District: Physiography," Trans. N.Z. Inst., vol. xliii, pp. 319–20, 1911; "The Intermontane Basins of Canterbury," ibid., vol. xlvii, pp. 336–53 (p. 353), 1915.

The folds of this system have sometimes been regarded as trending uniformly north-east and south-west parallel with the elongation of the existing ranges in which the rocks occur,[1] and from this it might be inferred that they determine the north-east and south-west trend

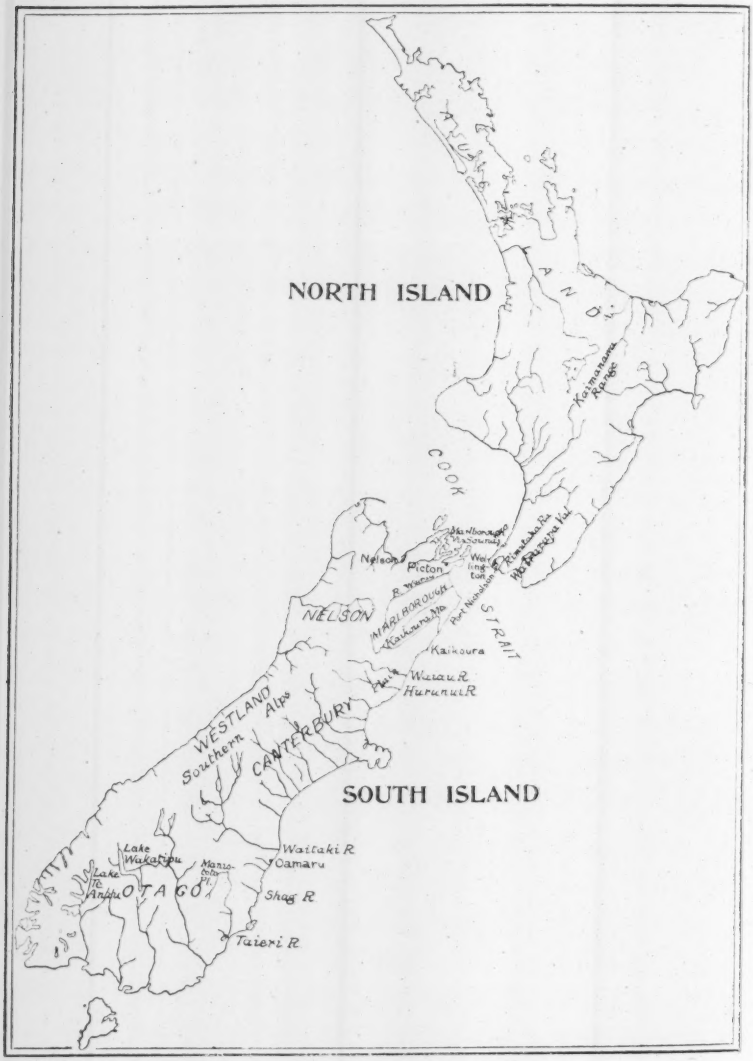


FIG. 1.—Locality map of New Zealand.

[1] See, for example, P. Marshall, "New Zealand and Adjacent Islands," Handbuch der regionalen Geologie, Bd. vii, Abt. i, p. 58, Heidelberg, 1911; *Geology of New Zealand*, Wellington, 1912, p. 127.

of the land masses of the South Island and the southern part of the North Island, an inference that has apparently been drawn by Gregory, who includes the coasts of Central New Zealand with those of his "primary Pacific type" [1]. Such an inference is probably not true for any part of the coast of New Zealand. In the southern part of the North Island—in the vicinity of Wellington, for example—the discordance of the trend of the folds with that of the shore-line is shown clearly by the *en echelon* arrangement of the ridges which may be noted from any high point of view, ridge after ridge and valley after valley of the subsequent features developed by erosion on these strata being obliquely truncated by the western coast. The trend of the ridges, corresponding with the general direction of the strike of the rocks, is only 10° to 15° east of north, while that of the coast is north-east, parallel with the elongation both of the mountainous axis of the island and of the land mass as a whole. Some of the north-east trending coasts of Central New Zealand have recently been described by the writer as resulting from faulting of comparatively modern date.[2]

In the South Island there appears to be by no means a close agreement between the trend of the major features and that of the folds of the oldermass. Scattered observation of the strike made by the writer in the north-east of the island show that it is very variable, but the average trend appears to be the west of north. Observations by McKay in the same district also indicate great variability,[3] and both McKay [4] and Hutton [5] have noted a more or less definite dome and basin structure. In the main ranges of the Southern Alps the average strike of the rocks was noted by Dobson to be N. 22° E. (*fide* Haast). Haast [6] and later observers, particularly Morgan [7] and Speight,[8] record great variability in that area also. In the study of the major relief features of New Zealand the trend of the Mesozoic folds may be almost entirely disregarded, for these features have been blocked out by much later orogenic movements, and the deformed strata of the oldermass, when affected by the latter movements, have generally behaved like resistant massive rocks.

[1] J. W. Gregory, "The Structural and Petrographic Classification of Coast Types": Scientia, vol. xi, pp. 36–63, 1912.

[2] "Fault Coasts in New Zealand": Geog. Rev., vol. i, pp. 20–47, 1916.

[3] A. McKay, "On the Geology of the East Part of Marlborough," Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl., 1885, pp. 27–136, 1886; "On the Geology of Marlborough and South-East Nelson," ibid., 1888–9, pp. 85–185, 1890.

[4] F. W. Hutton, "Report on the Geology of the North-East Portion of the South Island": Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl., 1873–4, pp. 27–58, 1877 (p. 32).

[5] A. McKay, "On the Older Sedimentary Rocks of Ashley and Amuri Counties": Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl., 1879–80, pp. 83–107, 1881 (p. 85).

[6] J. von Haast, *Geology of the Provinces of Canterbury and Westland*, Christchurch, 1879.

[7] P. G. Morgan, "The Geology of the Mikonui Subdivision, North Westland," N.Z. Geol. Surv., Bull. 6, 1908; "A Note on the Structure of the Southern Alps," Trans. N.Z. Inst., vol. xliii, pp. 275–8 (p. 277), 1911.

[8] R. Speight, "The Mount Arrowsmith District: Physiography": Trans. N.Z. Inst., vol. xliii, pp. 317–42 (p. 319), 1911.

A Period of Erosion and Deposition following the Mesozoic Orogenic Movements.

Upon the eroded surface of the oldermass lies a series of covering strata, and there can be no doubt that the mountain ranges which resulted from the Mesozoic orogenic movements had been subjected to erosion throughout a long period and reduced to at least moderate relief before the deposition of the oldest (Cretaceous) beds of this cover. It remains uncertain, however, whether at this stage complete peneplanation had been effected over any considerable area. In North Canterbury, indeed, Speight[1] has noted changes of facies in the limestone horizon of the covering strata, and there is certainly overlap in the lower beds, indicating that the eroded surface of the oldermass was there still somewhat hilly when submergence began, and that some hills survived as islands during a portion of the period of deposition of the cover. The available evidence points, however, to practically complete submergence of a large part of the north-eastern district of the South Island in the period of deposition of the Amuri Limestone (perhaps Eocene), and in some parts much earlier. The open-water origin and wide original extension of the Amuri Limestone have been demonstrated by McKay[2] and Hector.[3] Hector's brief statement may be quoted: "All these formations enter into great flexures that have been eroded to form lofty mountains, and the evidence is complete that they at one time spread continuously over a wide area. This view is therefore completely opposed to the suggestion that has been made that the upper calcareous members of the Waipara formation were deposited among islands and in land-locked inlets after the erosion of the present valley systems."[4]

In the Marlborough area there was a long period of uninterrupted deposition extending far into the Tertiary, though to what stage of the Tertiary is not yet satisfactorily established. At this juncture great but quite local uplift occurred in certain areas, probably by block faulting, leading to the deposition in the neighbouring undisturbed areas of that remarkable formation the Great Marlborough Conglomerate.[5]

During the early part of the long period of deposition in Southern Marlborough the neighbouring Marlborough Sounds district to the north and the South-Western Wellington district to the north-east appear to have escaped submergence, for the basal portions of the few small remnants of covering strata, namely, a small area at

[1] R. Speight, "The Intermontane Basins of Canterbury": Trans. N.Z. Inst., vol. xlvii, p. 350, 1915.

[2] A. McKay, "On the Geology of the East Part of Marlborough," Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl., 1885, pp. 27–136, 1886; "On the Geology of Marlborough and the Amuri District of Nelson," ibid., 1888–9, pp. 85–185, 1890; "On the Geology of Marlborough and South-East Nelson," pt. ii, ibid., 1890–1, pp. 1–28, 1892 (see pp. 5–7).

[3] J. Hector, Col. Mus. and Geol. Surv. N.Z., Progress Report for 1885, 1886; Progress Report for 1888–9, 1890.

[4] Progress Report for 1885, p. xviii.

[5] C. A. Cotton, "On the Relations of the Great Marlborough Conglomerate . . .": Journ. Geol., vol. xxii, pp. 346–63, 1914.

Picton [1] and one in the Makara Valley, Wellington,[2] are regarded as of Tertiary age. The exposures are so poor in each case that the form of the surface on which the beds were deposited cannot be ascertained. We are not under the necessity of believing that the surface must by that time have been reduced to a plain, for it may have been rejuvenated from time to time by uplift, though adjoining areas where deposition was in progress were sinking. It is quite possible that portions of these districts have never been submerged since first uplifted by the Mesozoic movements, though the sculpturing to which they owe their present mountainous character followed much later uplift. Planation may well have happened more than once in the long intervening period. North-eastward of Wellington there is no evidence of submergence having taken place until rather late Tertiary times.[3]

Farther to the north, in the centre of the North Islands, Speight [4] notes the presence of a plateau surface truncating the structure of the oldermass in the Kaimanawa Mountains, which he ascribes to marine erosion. The surface presumably passes under and forms the floor of the Tertiary beds (referred to the Miocene) of that district, which occur up to the height of 3,700 feet above sea-level. It appears probable from Speight's description that the covering strata were formerly continuous across the island in the Kaimanawa area, and that the plateau of the higher part of the range has been stripped of its cover by erosion.

In the south-eastern and north-western parts of the South Island the covering strata, with the exception of some of the basal beds, are mainly marine and of such a nature as to indicate that they accumulated in an open sea where the supply of terrigenous sediment was very small. Though the total area over which these rocks now occur is not large, their former extension over a much wider area is proved by the presence of outliers.

From the above considerations and from a general survey of what is known of the Tertiary rocks it is apparent that during the period of their deposition a great part of the site of the present islands of New Zealand was continuously submerged, and that very little of the remainder was left above water.

It is important to note that the members of the covering strata, whether always strictly conformable or otherwise, appear to follow one another without discordance of dip, no satisfactory evidence to the contrary being known. Thus it may be stated that, except quite locally,[5] the only movements affecting the region after the

[1] A. McKay, Geol. Surv. N.Z., Rep. Geol. Expl., 1890, pp. 153–4.

[2] A. McKay, "Report on Tertiary Rocks at Makara": Col. Mus. and Geol. Surv. N.Z., Rep. Geol. Expl., 1874–6, p. 54, 1877.

[3] J. A. Thomson, "Mineral Prospects of the Maharahara District, Hawke's Bay": 8th Ann. Rep. Geol. Surv., Mines Statement, 1915, p. 165.

[4] R. Speight, "Geological History" in L. Cockayne's *Report of a Botanical Survey of the Tongariro National Park*, Department of Land, C. 11, Wellington, 1908, p. 7.

[5] The hypothetical block movement which has been assumed in order to account for the Great Marlborough Conglomerate has been referred to on an earlier page. In a paper on the "Structure of the Paparoa Range", read before the Geological Section of the Wellington Philosophical Society,

Mesozoic orogenic period until near the end of the Tertiary were epeirogenic. This is contrary to the view of Hutton,[1] who believed that folding movements affected the Cretaceous rocks in early Tertiary times, before the deposition of the remainder of the covering strata.

The Kaikoura Orogenic Movements.

The orogenic movements which followed the Tertiary deposition, and to which the present relief is entirely or almost entirely due, must have occurred in or about the Pliocene period. The period of movement may be termed the "Kaikoura orogenic period", since the Kaikoura ranges were the first to be explained by Hector[2] and McKay[3] as owing the whole of their elevation to these late earth-movements. It cannot, however, be definitely stated at present whether the orogenic movements began contemporaneously all over the region. Far too little is known as yet of the ages and correlations of the members of the covering strata to allow us to arrive at a conclusion on this point.

The immediate cause of the disturbance may have been compression, for, in Central New Zealand at least, compression in a north-west and south-east direction accompanied the movements. In Marlborough the uplifted and depressed areas are elongated with a north-easterly trend, and major faults, some of which are certainly reverse faults, trend in the same direction, as do also folds in the previously horizontal covering strata. Perhaps owing to the rigidity of the oldermass, the strata of which had previously been folded on other lines and would strongly resist the new folding, the region was broken up into a number of 'blocks' bounded on one or more sides by faults, folding being generally subordinate to faulting except in the higher members of the covering strata, where the resistance of the rigid floor had least effect.

In recent years, wherever detailed geological work has been done, evidence has accumulated of the importance of the part played by young faults in the structure of New Zealand, as may be found by reference to the accounts of the structure of parts of Westland, Nelson, Otago, and Auckland by Bell, Morgan, Park, Henderson, and others in the bulletins of the Geological Survey, and to a paper by Henderson[4] in which much information regarding faults in Western Nelson is brought together.

While in a few cases the recognition of these faults rests on the evidence of fault-scarps or fault-line scarps, the majority of the faults described are such as bring the covering strata against the older rocks. Many other faults less easily detected by purely geological

August 18, 1915, Dr. J. Henderson stated that in Western Nelson a succession of similar movements had taken place. In these cases, however, during and after the movement, accumulation of sediment went on in the immediate vicinity on an undisturbed sea-floor.

[1] *Geology of Otago*, Dunedin, 1875, p. 76.

[2] Progress Report, Rep. Geol. Expl., 1888–9, p. liv, 1890.

[3] "On the Geology of Marlborough and South-East Nelson," pt. ii: Rep. Geol. Expl., 1890–1, p. 7, 1892.

[4] J. Henderson, "On the Genesis of the Surface Forms and Present Drainage-systems of West Nelson": Trans. N.Z. Inst., vol. xliii, pp. 306–15, 1911.

methods also occur. The long straight fault-lines shown on the map by McKay[1] and the later maps by Park,[2] connecting up known portions of faults, must of necessity be highly hypothetical, and they probably fall far short of representing the facts; but it is true, nevertheless, that to McKay belongs the credit of being the first to recognize the importance of faults in determining the physical features and geological boundaries.

McKay's views are strongly opposed to those of Hutton, who conceived only of regional (epeirogenic) movements of uplift and subsidence in later geological times.[3] Hutton recognized no young faults and no orogenic movements later than those at the close of the Jurassic except "a certain amount of folding" restricted to certain localities, which, he believed, took place "at the commencement of the Tertiary".[4]

"Not only," he wrote, "was the last touch given at this time [commencement of the Tertiary] to the geological structure of the [Southern] Alps, but the chief valleys were also marked out at this period.

"For example, we find our oldest tertiary rocks occupying the valley of the Waitaki . . . and the Maruwhenua . . . In the valley of the Shag they extend up nearly to its source. . . ."[5]

To the explanation of the geological history of New Zealand thus expressed in 1875 Hutton afterwards closely adhered, as will be gathered from the following statements as to supposed changes in river courses, which are based on the assumption that the present relief has survived from very ancient times. This represents Hutton's opinion in 1899: "The Shag River at one time drained the Maniototo Plains until the gorge of the Upper Taieri was cut. In early Cretaceous times the Hurunui and Waiau-ua united and entered the sea at Kaikoura. At a later time they turned down the Weka Pass, and it was not until the Pliocene period that each cut its own valley to the sea. The Upper Manawatu flowed into the Wairarapa, and in the older Pliocene a river ran from the Manawatu gorge to Napier. The courses of all these rivers were changed by the deposition of marine rocks in the valleys, which blocked them; and this, on the subsequent rise of the land, caused the rivers to overflow to one or the other side, according to the position of the lowest opening."[6]

The depressions, such as the Shag Valley and that extending from the Waiau to Kaikoura, regarded by Hutton as eroded valleys and assigned by him in the foregoing passage to ancient courses of various rivers, are more satisfactorily explained as tectonic features which came into existence in the Kaikoura period.

[1] N.Z. Rep. Geol. Expl., 1892, p. 1.
[2] J. Park, *Geology of New Zealand*, Christchurch, 1910, pp. 263, 265.
[3] *Geology of Otago*, Dunedin, 1875, pp. 77–85 and pl. ii.
[4] Loc. cit., p. 76.
[5] Loc. cit., p. 77; cf. also "Sketch of the Geology of New Zealand", Quart. Journ. Geol. Soc., vol. xli, p. 196, 1885.
[6] "The Geological History of New Zealand": Trans. N.Z. Inst., vol. xxxii, p. 180, 1900.

(*To be concluded in our next Number.*)

III.—The Crystalline Rock Areas of the Piémontese Alps.

By C. S. Du Riche Preller, M.A., Ph.D., M.I.E.E., F.G.S., F.R.S.E.

(*Concluded from May Number, p. 205.*)

III. The Dora Riparia Group. (Figs. 3 and 4.)

In this group, shown in the sketch-plan Fig. 4, may be included the interesting pietre verdi areas (1) of the Rocciavré ridge on the right, (2) of Monte Rocciamelone on the left side of the Dora Riparia Valley, and (3) of the Rocciacorba ridge and the Avigliana belt of spurs where the Dora and the Sangone Rivers emerge from the Alps and enter the Po Valley about 20 kilometres west of Turin.

1. *The Rocciavré Area.*—This ridge, about 12 by 4 kilometres in length and width, forms the divide between the Dora Riparia and Chisone Valleys, north and south respectively, while its eastern end lies at the head of the short valley of the Sangone torrent which discharges into the Po at Moncalieri south of Turin. Although the ridge derives its name from Monte Rocciavré, the latter (2,778 m.) is only one and not the highest of a remarkable cluster of pietre verdi peaks ranging from 2,600 to 2,900 metres in altitude. Of these the most notable are Rocciavré, Cristalliera (2,801 m.), Pian Real (2,617 m.), and Rocca Rossa (2,391 m.) at the eastern, Gavia (2,841 m.), Rocca Nera (2,852 m.), and Mezzodi (2,777 m.) at the northern, and the highest peak Orsiera (2,878 m.) at the western end, the elevation thus decreasing from west to east. The whole ridge obviously represents a former extensive pietre verdi sheet or cupola cut up by erosion and atmospheric denudation into resistant peaks which are separated by high *colli* or saddles of about 2,500 metres altitude.

The high-level pietre verdi area is accessible either from Perosa in the Chisone Valley (700 m.) or from Bussoleno (500 m.) in the Dora Valley, on which latter side the flanks of the ridge are deeply cut by several torrents in cascade gullies or *orridi*.[1] On the Chisone or southern flanks one of the most remarkable exposures, pointed out by Gastaldi as early as 1876,[2] is that near Colle della Roussa, about 2,400 metres altitude, where the substratum of minute and tabular gneiss with intercalated crystalline limestone, steatite, and graphitic rock is overlain horizontally and conformably by a great bank of lherzolite more or less altered to serpentine, both compact and schistose, upon which rests an equally high bank of euphodite largely metamorphosed to amphibolic and epidotic rock with smaragdite, and to glaucophanic prasinites. The total thickness of this pietre verdi exposure is at least 200 metres.

Unlike the southern or Chisone flanks, which form part of the gneissic-graphitic zone, the northern or Dora Riparia flanks of the ridge exhibit from Bussoleno (500 m.) upwards the normal

[1] These cascade gullies, varying from 100 to 300 metres in height, are characteristic of the mountain-sides of the Dora Riparia Valley, and are locally called *orridi* both from their weird, forbidding appearance and the enormous quantities of detritus and débris brought down through them by the torrents when in flood.

[2] Boll. R. Com. geol., 1876, p. 108.

Fig. 2. SECTION OF MONTE VISO.

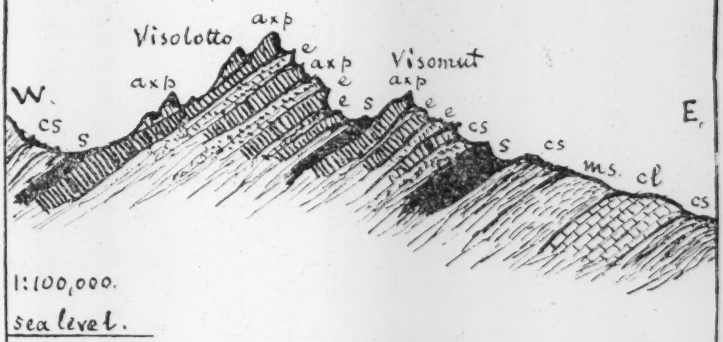


Fig. 3. SECTION OF ROCCIAMELONE.

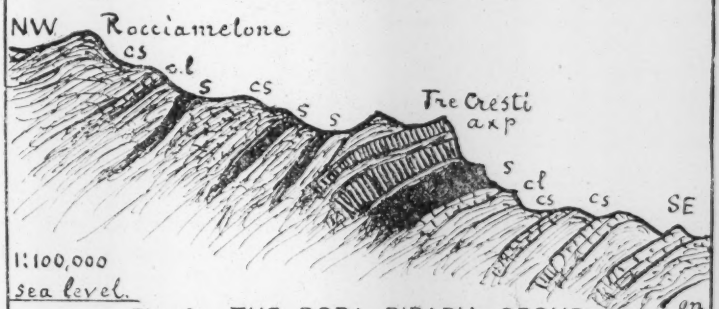


Fig. 4. THE DORA RIPARIA GROUP.

Rocciavre, Rocciamelone, Rocciacorba and Avigliana.

cs = calc-schist; ms = mica-schist;

cl = crystalline limestone; s = serpentine; e = euphodite;

axp = amphibolites and prasinites.

Del. D.R.P.

crystalline sequence of mica-schist with gneiss intercalations at the lower, and calc-schists with pietre verdi at the higher levels. The Bussoleno gneisses, quarried on the right of the Dora down to Villar Focchiardo, differ greatly from the primitive, large-grained, glandular, eye-gneiss of the Dora–Maira massif which crops out on both sides of the valley from Villar Focchiardo to S. Michele. Those younger, intercalated gneisses are of the minute and tabular type, in part with porphyroid and eye-structure, more or less tourmaliniferous, often rich in albite and poor in mica, or vice versa, while the mica-schist is frequently garnetiferous.[1] Such gneiss intercalations also occur higher up the ridge, where they are associated with omphacitic eclogite and prasinite.

The pietre verdi area of the ridge as a whole may be described as composed of peridotitic, serpentinous, and euphoditic masses extending in the shape of a triangular trough from the Orsiera peak at the western to Colle della Roussa at the southern, and to Rocciavré, Pian Real, and Rocca Rossa at the eastern end, while euphodites and prasinites predominate more especially in the Rocca Nera and Mezzodi peaks in the centre of the northern part. The serpentinous masses reach their maximum thickness of about 300 metres in the Orsiera and of 500 metres in the Pian Real peak. The contact between serpentine, euphodite, and prasinite is generally marked by serpentinous, chloritic, and actinolitic schist, and in places by eclogite with large uralitized omphacite crystals, while the chloritic schist, e.g. between Pian Real and Rocca Rossa, contains diallagic, viz. smaragdite, crystals of unusually large size.[2] The euphodites present a great many varieties and are, as usual, largely altered to their prasinitic and zoisitic derivatives.

In the total rise of 2,300 metres from the valley floor near Bussoleno to the crest-line of the ridge, the garnetiferous mica-schists, with tourmaliniferous gneiss intercalations and quartzite, occupy about 1,200 metres, followed by about 600 metres of calc-schist with intercalated prasinitic and serpentinous schist, and lastly by about 500 metres of pietre verdi forming the cupola of the ridge.

The ravine of the Sangone east of the ridge to Giaveno, where the torrent enters the Po Valley, is deeply and entirely eroded in the gneiss and mica-schist of the Dora–Maira massif without pietre verdi, but in other directions the Rocciavré group is linked with large pietre verdi areas both past and present. Thus, on the north the pietre verdi extend across the Dora Valley to Rocciamelone and the Lanzo valleys, while west, south-west, and south a large number of small intermittent outcrops afford evidence of a former extensive area which lay in the great syncline of the calc-schist formation 20 to 25 kilometres in

[1] The gneisses of Bussoleno are among those regarded by Professor Gregory as intrusive and Pliocene ("Waldensian Gneisses": Q.J.G.S., 1894, p. 232 et seq.). His views were traversed in detail by Franchi, "Appunti Monti di Bussoleno": Boll. R. Com. geol., 1895, p. 177 et seq., and by Novarese, "Rilevamento Valle Germanasca": ibid., 1895, p. 277 et seq.; also by Stella, "Valli Orco e Soana": ibid., 1894, p. 349, footnote.

[2] Franchi mentions such crystals up to 20 centimetres in length. Op. cit., 1895, p. 3 et seq.

width,[1] and connected the Rocciavré group with the similar groups of Oulx, Chaberton, Genèvre, Maurin, Chabrière, and Monte Viso.

2. *The Rocciamelone Area.*—This imposing mountain, the ancient *Mons Romuleus*, with its peaked summit rises straight from the Dora Riparia on the right of the valley at Susa (503 m.) to an altitude of 3,537 metres in a horizontal distance of only 7 kilometres. The most accessible ascent is from Susa or, further down the valley, from Bussoleno. The massif lies in the calc-schist horizon, which also includes the series of similar high peaks immediately north of it, as far as the Levanna and Gran Paradiso gneiss massif. From the summit and the sanctuary of Madonna della Neve down the southern flank the calc-schist alternates at first with micaceous schist, lenticular masses of bluish and white crystalline limestone, serpentine with ophicalce or green marble, and amphibolites and prasinites, as far as the spur of Tre Cresti. From this point in an oblique direction towards Bussoleno and Chianoc, the alternations of calc- and micaceous schist with pietre verdi become more frequent, and nearer the valley floor are replaced by minute and tabular gneiss, intercalated masses of crystalline limestones, and the fossiliferous calcareous beds of Chianoc and Foresto.

On this southern flank, shown in the section Fig. 3, the pietre verdi exhibit remarkable aggregations of amphibolic and prasinitic rocks with both massive and schistose serpentine, which latter becomes so predominant as to eclipse the calc-schist altogether. Especially is this the case in and above the Rio Muletta gorge, which descends to Bussoleno from the Croce di Ferro ridge, and exhibits an almost perpendicular cliff of serpentine no less than 500 metres in height, overlain by another 500 metres of amphibolites and prasinites. The serpentine cliff rests on crystalline limestone which then alternates with calc- and serpentine-schist down to the minute and tabular gneiss near Chianoc, the latter belonging to the same horizon as the Bussoleno gneisses on the opposite side of the valley. Lower down the valley, as already mentioned, the typical primitive, glandular gneiss with large elements and greyish-green mica appears on both sides, extending on the left to St. Didero, Borgone, and Condové, and on the right to St. Antonino, Vayes, and the *chiusa* or defile of S. Michele. In this section of about 12 kilometres the bed of the Dora Riparia is therefore eroded entirely in primitive gneiss, which here forms the northern extremity of the Dora–Maira gneiss massif.

The crest of the great ridge of peaks and crags which runs on the left of the Dora from Rocciamelone eastward for about 36 kilometres to the spur of Monte Musiné, north-east of Avigliana, is almost entirely composed of pietre verdi with only a few narrow outcrops of calc-schist in the intervening eroded saddles or *colli*. As this ridge forms more properly part of the area of the Lanzo valleys, I shall refer to it again in connexion with that region.

[1] The calc-schist formation extends north-west, and entirely encircles the mica-schist and minute gneiss massif of Rocca d'Ambin (3,377 m.), about 20 by 10 kilometres in length and width, which lies between the upper Dora Riparia Valley on the Italian and the Are Valley on the French side, and at its northern extremity is crossed by the Mont Cenis road from Lanslebourg to Susa.

3. *The Rocciacorba and Avigliana Area* (Fig. 4).—This area is of special interest, owing alike to its complex nature and its singular configuration, and also because of its vicinity to Turin, whence it is easily reached by Rivoli, Giaveno, or Avigliana. As already mentioned, the eastern spurs of the Dora Riparia and Sangone Valleys converge to a horseshoe or amphitheatre—about 25 kilometres in circumference and 10 kilometres in width—in the centre of which lies Avigliana. The southern end of the horseshoe, on the right of the Sangone, is formed by the Pietraborga spur (926 m.) of the Rocciacorba ridge, the middle or western part by the Ciabergia (1,178 m.) and Sacra S. Michele (962 m.) spurs between the Sangone and Dora Riparia Valleys, and the northern bend, on the left of the Dora, by the promontory of Torre del Colle (600 m.), and the mountain-side comprising, among others, Rocca della Sella (1,508 m.), Monte Curto (1,325 m.), and, at the eastern extremity, Monte Musiné (1,150 m.). Across the centre of the horseshoe, as a connecting link between the Pietraborga and Torre del Colle spurs, stretches the low Moncumi (642 m.) and Avigliana ridge, and between this and the Ciabergia or western spur lie, in an old morainic depression, the two small lakes of Avigliana (452 m.). From the Moncumi ridge eastward spread the enormous glacial and alluvial deposits of the Dora Riparia, sloping down towards Rivoli and Turin.[1] On the rugged and precipitous flanks of the horseshoe, patches of glacial deposits reach up to 900 metres altitude or 500 metres above the valley floor, but the continuity of the rock formations can be traced all round the crags and in the numerous gullies or *orridi* of the different spurs.

The pietre verdi of this area lie in the horizon of minute gneiss and mica-schists, which are, however, in evidence only in outcrops on the western margin, at the base of the primitive gneiss, and therefore in reversed sequence, as the continuation of the corresponding reversal further south, already referred to. The minute gneiss and mica-schists with crystalline limestone form banks of considerable thickness on the Ciabergia and S. Michele ridge where they are quarried. Together with the pietre verdi on their eastern margin, they are the continuation of the gneissic, dioritic, and peridotitic belt of the Rocciacorba ridge, which, about 8 by 3 kilometres in length and width and about 900 metres in altitude, extends from Monte S. Giorgio, near Piossasco, on the south, to the Pietraborga spur above Trana at its northern end. The crest-line of this ridge exhibits in succession the masses of garnetiferous and graphitic mica-schist and minute gneiss, lherzolite, serpentine, and dioritic rocks with associated eclogite, and amphibolic and prasinitic schists which constitute the series and reach their greatest thickness in Monte Montagnazza (892 m.).

From the Pietraborga spur the pietre verdi radiate N.W., N., and N.E. in several more or less defined zones, of which the western follows the Ciabergia ridge, crosses the Dora Riparia at S. Michele, and reappears on the left bank at Chiavrié, while the middle zone, starting from the same point, forms the Moncumi and Avigliana ridge

[1] Of this "Morainic Amphitheatre of Rivoli", Professor F. Sacco has given an interesting description in Boll. R. Com. geol., 1887, p. 141 et seq.

between the Sangone and the Dora, and reappears on the left of the latter at Torre del Colle ; and a third zone, bifurcating from the second at the Moncumi ridge, crosses the Dora, and, running north-east, forms the Musiné spur. Within the Avigliana horseshoe, the pietre verdi thus attain a visible thickness of 500 metres in Monte Pietraborga, of 700 metres in the Ciabergia ridge, and of 1,200 metres and more on the mountain-side left of the Dora, whence the series continues north for about 25 kilometres along the eastern spurs to Lanzo. It is in this belt that the peridotitic masses, lherzolite and serpentine, with associated euphodite, are more especially predominant. In places, e.g. in the Musiné spur, the lherzolite is so decomposed that it is quarried for the extraction of magnesite.[1] All the pietre verdi masses of the Rocciacorba and Avigliana area dip at more or less steep angles, in some places are almost vertical, and throughout are much contorted.

The three groups of the Dora Riparia area, viz. of Rocciavré, Rocciamelone (in the triangle Susa, Chianoc, and summit) and Avigliana, including Rocciacorba, cover each about 50, in the aggregate 150 square kilometres, or about 60 square miles, equal to the superficial area of the Monte Viso group. The conclusions as to the age and origin of the pietre verdi groups of Southern and Western Piémont considered in the present paper, will be stated in connexion with the areas of Northern Piémont to be dealt with in the sequel.

IV.—The Origin of Topaz and Cassiterite at Gunong Bakau, Malaya.

By William R. Jones, D.Sc. (Lond.), F.G.S.

TOPAZ is commonly supposed to have been formed by the action of fluorine-bearing vapours on felspar, but evidence has recently been advanced with the object of showing that some important veins intrusive in the porphyritic granite of Gunong Bakau, a mountain 4,426 feet high, situated in the centre of the Main Granite Range of the Malay Peninsula, were formed of a rock in which "the topaz and cassiterite are not alteration products of previously formed minerals".[2] The author of this theory gives the rock the descriptive name of 'quartz-topaz', and adds as his reasons for not calling it 'greisen' the fact that in places it contains very little mica and that, unlike the majority of greisens, it is not an alteration product.

The writer is very familiar with the area in which these rocks occur, and in a report[3] written in 1913 called attention, for the

[1] The quarried exposure of lherzolite with euphodite and magnesite is on the south-east slope of Monte Musiné, above Casellette (505 m.). About 8 kilom. east of this point, midway between it and Turin, lies, at Pianezza, in the morainic area, Roc Gastaldi, an erratic monster-block of euphodite measuring 30 by 12 by 14 metres in length, width, and height = 5,000 cubic metres or over 10,000 tons. It is surmounted by a small chapel.

[2] J. B. Scrivenor, "The Topaz-bearing Rocks of Gunong Bakau": Q.J.G.S., vol. lxx, p. 363, 1914.

[3] W. R. Jones, *Preliminary Report of Mining in the Main Granite Range, Federated Malay States*, 1913.

first time, to their importance as a source of tin-ore. The object of the present paper is to adduce evidence in support of the generally accepted theory for the origin of this topaz and cassiterite, and against that of their primary origin. It is not suggested that topaz and cassiterite *never* occur as primary minerals, for cases are known where the evidence appears conclusive that they can so occur on a small scale, but for the present attention will be confined to this particular locality, where the occurrence is on a large scale and of economic importance.

The veins of 'quartz-topaz' vary in thickness from about 15 feet to less than an inch, and in some places have now been extensively worked for tin-ore, notably on the mines of Messrs. Bibby and Ruxton and adjoining mines.

The difficulties against accepting the ordinary theory for the genesis of the topaz in these veins are clearly set forth by the author of the paper referred to, and may be summarized as follows: the absence of alteration in the country rock; the dissimilarity between the vein rock and rock in the same locality that is clearly an alteration rock; the presence in some of the rock of an iron-rich zinnwaldite which is different from the neighbouring secondary mica; the marked difference between the tin-ore bodies known to be of secondary origin and the bodies of ore in these veins.

The absence of alteration in the country rock in the locality under consideration does not appear to be more pronounced than in other tin-fields where topaz and cassiterite have clearly been shown to be of secondary origin. The dark borders to these veins are stated to be "the result of reaction between media that came off from the vein rock and the porphyritic granite, and a portion of the original vein rock",[1] and to contain a little topaz and an abundance of tourmaline. Also the granite country rock "is altered for a few inches by emanations from the vein rock to form familiar pneumatolytic modifications".[2] This alteration is certainly as extensive as is the case in places at Geyer and Ehrenfriedersdorf, areas in the Erzgebirge tin-field, for there the alteration of the country rock is for a distance of only 2 to 6 inches,[3] whereas in the Graupen area the country rock of the Luxer cassiterite-bearing vein has not been altered at all into greisen.[4] That the topaz and cassiterite of the Erzgebirge tin-field is of secondary origin has been very conclusively established, for the mine exposures in Altenberg Zwitterstock show "that the impregnation has been confined to the *upper portion* of the granite", and that "at a depth of 700 feet normal granite is encountered, in which zwitter bands are completely lacking or only sparingly present".[5]

The writer's observations of various tin-lodes have led him to the conclusion that the amount of alteration of the country rock is

[1] J. B. Scrivenor, op. cit., p. 370.
[2] Ibid., p. 375.
[3] J. T. Singewald, jun., "The Erzgebirge Tin Deposits": *Economic Geology*, vol. v, p. 267, 1910.
[4] Ibid., p. 177.
[5] Ibid., p. 171.

sometimes extremely irregular even in the same vein, but is greatest, in general, where the rock contains a network of small fissures filled with ore. There are, however, exceptions to this, for at the Chendai and Menglembu lode-veins in Kinta, Malaya, where felspar crystals are cut by minute cassiterite-bearing fissures, the felspars, as has been previously pointed out by Mr. Scrivenor,[1] are quite fresh. The writer saw an interesting case at Serendah, Malaya, where the absence of alteration in the country rock of a lode appeared to be due to its coalescence with another lode, exposed later, and through which the mineralizing vapours found an easier conduit.

The dissimilarity between the vein rock and the adjacent alteration rock is only what would be expected, for the rock intruded as veins in the consolidating granite was the more acid part of the differentiated magma and formed, before being subsequently acted upon by an abundance of fluoriferous mineralizers, an aplite or pegmatite vein rich in quartz, felspar, and little or much mica, such as are so very frequent in this neighbourhood. It is not the rule, but rather the exception, to find the peripheries of cassiterite-bearing veins similar in mineral content to the central parts of the vein, especially where the veins are thick. The footwalls of tin-lodes are, in general, richer in ore than the hanging walls and very considerably richer than in the body of the lode; and where wolfram, for example, occurs associated with tin-ore the former frequently occurs sporadically as coarse crystals along the walls. At Zinnwald [2] quartz and zinnwaldite occur in a lode as layers in such a way that the individual layers are parallel to the walls, and one of these may occur to the almost complete exclusion of the other.

The presence in these 'quartz-topaz' veins of an iron-rich zinnwaldite seems to support, rather than contradict, the secondary origin of the topaz and the cassiterite, for zinnwaldite is also abundant in the veins in the Erzgebirge tin-field. At Zinnwald in this district "the chief gangue minerals are quartz and zinnwaldite".[3] It will also be shown later that the addition of iron takes place in the process of greisenization in districts where chemical analyses of the greisen and the unaltered rock are available.

Emphasis is given to the marked difference between the ore-bodies occurring at Gunong Bakau, admitted to be of secondary origin, and the ore-bodies in the veins where the topaz and cassiterite are presumed to be of primary origin. The ore-bodies worked at Gunong Bakau occur mainly in four types of lodes: (1) The rock at Hemy's Lode, which has been described elsewhere[4] by the writer, is not sufficiently coarse-grained for a typical pegmatite, and although more acid than ordinary granite, is best described as an altered medium-grained granite, very rich in quartz, mica (some being secondary), tourmaline, and cassiterite, relatively poor in felspar, and containing

[1] J. B. Scrivenor, *The Geology and Mining Industry of Kinta District, Federated Malay States* (Kuala Lampur), 1913, p. 62.

[2] J. T. Singewald, jun., "The Erzgebirge Tin Deposits": *Economic Geology*, vol. v, p. 173, 1910.

[3] Ibid.

[4] W. R. Jones, "Mineralization in Malaya": *Min. Mag.*, vol. xiii, No. 4, p. 198, Oct. 1915.

a little fluorite; (2) the 'quartz-topaz' rock carrying tin-ore and (3) the 'topaz-aplite' at Messrs. Bibby & Ruxton's mine; (4) pegmatite veins, composed mainly of milky quartz, in mines near by.

The differences in the gangue of these lodes do not appear to be more striking than in numerous other areas in Malaya and in other tin-fields, and not even so marked as in some. It might even be said that variations equally great have been observed elsewhere in different parts of even the *same* lode. The Luxer[1] vein at Graupen in the Erzgebirge tin-field, for example, is characterized by extremely variable filling. The prevailing gangue is milk-white quartz which locally gives place to coarsely crystallized orthoclase intergrown with albite, and to fluorite; also a dark-green lithia mica and a compact variety of kaolinite ('steinmark') occur as subordinate gangue minerals; and the cassiterite is usually evenly distributed, as in the Gunong Bakau veins. At Zinnwald, in the same tin-field, sulphides are confined *solely* to the middle of the veins, and the tin-lodes contain as essential constituents quartz and a greenish or brownish-green mica, whereas in the neighbouring area of Altenberg topaz is the predominant constituent. In this tin-field at Sadisdorf a lode[2] formerly worked for tin-ore is now worked solely for wolfram and molybdenite. Near the footwall occur large nests of pure wolfram, which together with the enclosing quartz are cut by secondary horizontal stringers of quartz carrying tin-ore and gilberite. These stringers are again cut by still younger vertical fluorspar stringers, and towards the hanging wall a great deal of molybdenite and also a little zinnwaldite are encountered, and bismuth and bismuthine also occur along both walls.

All the types of rocks found at Gunong Bakau in Malaya are also found in some other tin-fields, notably the Erzgebirge tin-fields, where "all stages of transformation from granite to greisen are encountered and frequently the greisen areas include unaltered masses of granite".[3] At Geyer the granite is locally converted to a rock containing more than 90 per cent of topaz.[4]

It is stated by Mr. Scrivenor "that the sequence of events in the mass forming Gunong Bakau is clear. First the porphyritic granite consolidated; then the quartz-topaz veins were intruded; and then the topaz-aplite arrived".[5] If the topaz in the quartz-topaz veins is a primary mineral the differentiation of the original magma must have taken place under extraordinary conditions, for a rock, free from felspar, is supposed to have been intruded after the first, containing porphyritic crystals of felspar, and before the third, which is described as being "rich in felspar". The absence of felspar in the second intruded rock is explained by supposing that "in the depths of the igneous mass there was a magma which, if undisturbed, would have crystallized out as a rock composed chiefly of potash

[1] J. T. Singewald, jun., "The Erzgebirge Tin Deposits": *Economic Geology*, vol. v, pp. 176–7, 1910.
[2] Ibid., p. 169.
[3] Ibid., p. 174.
[4] Solomon & His, Zeit. deutsch. geol. Ges., vol. xl, p. 250, 1888.
[5] J. B. Scrivenor, "The Topaz-bearing Rocks of Gunong Bakau": Q.J.G.S., vol. lxx, p. 378.

felspar".[1] This magma was then invaded by "a volume of gas as a huge bubble rising from below, *where it had been collected in a part of the magma on which it could not react*", and attacked "groups of molecules that would have solidified as felspar if they had not been disturbed by hydrofluoric acid"[2] (italics inserted, W. R. J.). The writer will not enter here into the question of the miscibility of silicate minerals in a magma which was sufficiently mobile to be intruded through long narrow veins, some less than an inch thick, nor on the possibility, or otherwise, of the accumulation of a huge bubble of vapour in the depths of an igneous mass, but will point out that no explanation is given of how a highly fluoriferous vapour can *collect* in a part of a magma on which it could not react. Moreover, a salic magma depends for its fluidity, as Bowen states,[3] "on its ability to retain volatile constituents," and the presence in such a magma of a free oxide, such as cassiterite, does not appear to be possible.[4] Especially is this the case in a magma which later emanated hydrofluoric acid.

In a footnote to p. 379 of his paper on these rocks the author has raised a question of great interest. He points out that "without segregation one could not expect to have a rock very rich in topaz", and gives figures to show that with a pure orthoclase magma only 32·6 per cent of topaz could be formed.

There is, however, an explanation why the percentage of topaz in a greisen does not necessarily depend on the percentage of felspar in the original rock. Researches on greisenization have shown that where it has been possible to obtain analyses of greisens and their neighbouring granites, some of the chemical changes involved appear to be as follows:—

According to	Addition of	Abstraction of
Vogt.[5]	SiO_2, B_2O_3, F (or HF), SnO_2, often also Li_2O, K_2O, and perhaps Al_2O_3.	CaO, MgO, Na_2O, and often also K_2O, Al_2O_3.
Dalmer.[6]	FeO, F, SnO_2, and possibly Al_2O_3.	K_2O, Na_2O, SiO_2.
Cotton.[7]	SiO_2, FeO, MgO, SnO_2, MoS_2, Al_2O_3.	—
Jones, W. R.	Al_2O_3, SnO_2, B_2O_5, HF, Li_2O, and possibly SiO_2.	K_2O, Na_2O.

[1] J. B. Scrivenor, "The Topaz-bearing Rocks of Gunong Bakau": Q.J.G.S., vol. lxx, p. 379.

[2] J. B. Scrivenor, *Mining Magazine*, February, 1916, "Discussion."

[3] N. L. Bowen, "The Later Stages of the Evolution of the Igneous Rock": *Journal of Geology*, supplement to vol. xxiii, No. 8, p. 16, 1915.

[4] A. Harker, *The Natural History of Igneous Rocks* (London, 1909), p. 166.

[5] J. H. L. Vogt, "Beiträge zur genetische Classification der durch magmatische Differentiationprocesse und der durch Pneumatolyse instanden Erzvokommen": *Zeit. prak. Geol.*, 1895, p. 146.

[6] K. Dalmer, "Der Alterberger-Graupener Zinnerslagerstättendistrikt": *Zeit. prak. Geol.*, 1894, p. 319.

[7] L. A. Cotton, "Metasomatic Processes in a Fissure Vein from New England": Proc. Linn. Soc. New South Wales, p. 231.

Messrs. Fergusson and Bateman,[1] as a result of their recent researches on greisenization from different localities, have come to the general conclusion that in the chemical changes involved there is an increase in silica, aluminium (which is only in part Al_2O_3), and probably of iron oxides, a loss of lime, magnesia, and the alkalies, the losses of the alkalies being approximately in proportion to the amount of each originally present, and only in slight degree selective. The following figures, extracted from analyses of granite and greisens, are instructive. In the cases of veins, the granite country rock would probably, however, be less acid than the former before greisenization.

	New South Wales.[2]			Erzgebirge.[3]			Gunong Bakau, Malaya.		
	Unaltered Granite.	Greisen away from vein.	Greisen near vein wall.	Unaltered Granite.	Greisen (quartz, mica, topaz).	Greisen (quartz-topaz).	Unaltered Granite.	Greisen (quartz, mica, topaz).	Greisen (quartz-topaz).
SiO_2 .	76·69	75·42	78·47	74·68	70·41	79·73	77·12	77·50	80·08
Al_2O_3 .	10·89	12·98	11·50	12·73	13·06[4]	10·24[4]	11·07	13·01	12·45
Fe_2O_3 .	0·76	1·68	2·64	—	1·42	—	1·17[5]	3·01[5]	0·09[5]
FeO, etc. .	0·39	0·58	1·05	3·00	5·09	—			

Conclusion.

The topaz-bearing rocks of Gunong Bakau bear striking similarities in their mode of occurrence and mineral content to those found in other tin-fields, and especially to those of Erzgebirge. The topaz and cassiterite in the latter tin-field have been proved to be of secondary origin, and the evidence appears to be very strong for presuming that these minerals are also of secondary origin at Gunong Bakau.

V.—Note on a gigantic Cephalopod Mandible.

By G. C. Crick, F.G.S., F.Z.S., of the British Museum (Natural History).

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THE British Museum has recently received (in the James W. Butler collection, presented by his daughter, Miss Daisy Butler) a particularly fine mandible of a gigantic fossil Cephalopod.[6] Unfortunately the locality of the fossil is not recorded, but as the collection contained quite a number of specimens from Bradford Abbas (Dorset) and the immediate neighbourhood, and the matrix of this specimen agrees very closely with that of those examples, there can be little doubt that the locality of the fossil is almost

[1] H. C. Fergusson & A. M. Bateman, "Geologic Features of Tin Deposits": *Economic Geology*, vol. vii, pp. 250–1, 1912.

[2] Ibid., p. 241.

[3] Ibid., p. 237.

[4] After deduction of part of Al, which formed 7·86 and 7·57 per cent of these rocks.

[5] Calculated as Fe_2O_3.

[6] British Museum (Natural History), Geol. Dept., reg. No. C. 18659.

certainly Bradford Abbas, or the immediate neighbourhood, and that the specimen is of Bajocian age.

The fossil (Fig. 2) is obviously the calcareous portion of the upper mandible of a giant *Nautilus*-like animal, as a comparison with that structure in the recent *Nautilus pompilius* shows.

The mandibles of *Nautilus pompilius* (see accompanying figures) were described by Sir Richard Owen[1] as follows:—

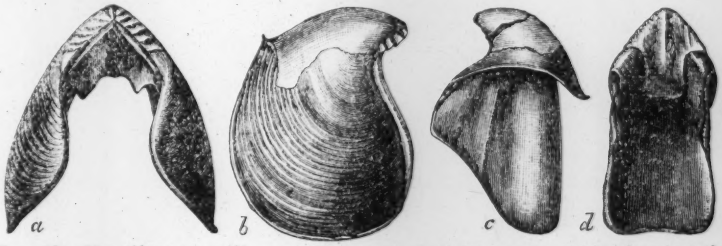

FIG. 1.—*Nautilus pompilius*. *a*, inner view of lower mandible showing the dentated margin of the calcareous upper part; *b*, lateral view of the same showing the widely-expanded horny laminæ of this mandible; *c*, lateral view of the upper mandible with its hood-like expansion; *d*, inner view of the same, showing the limits of the calcareous extremity of the mandible on the inner side. The calcareous extremities of the mandibles are indicated in figures *b*, *c*, *d* by lighter shading and a light irregular line showing the extent of the calcareous matter. This could not well be indicated in *a* without interfering with the dentated margin. Natural size. (After A. H. Foord, Cat. Foss. Ceph. Brit. Mus., pt. 2, 1891, fig. 76, p. 364.)

"These are two in number, having a vertical motion, and resembling in form the bill of the Parrot reversed, the upper mandible being encased in the lower when closed; they are adapted posteriorly to a muscular basis, to which they owe their motions. Thus far they resemble the mandibles of the Dibranchiate Cephalopods; but they are not composed entirely of horny matter, nor are they uniformly of a brown or black colour, their extremities being of a dense calcareous nature, and of a blueish white colour; they are also less pointed at the end; and the oral margins of the lower mandible are notched and dentated.

"They are proportionately larger than in the Cuttle-fish, each mandible measuring in length one inch and three lines, and in vertical breadth one inch. About half an inch from their anterior extremities the horny part separates into two laminæ, the exterior of which in the upper mandible is of little extent (from three to four lines), and is dilated and flattened above so as to form a triangular surface half an inch broad at the base. In the lower mandible the proportions of the two laminæ are reversed, the exterior one being produced to the full extent, so as to make it appear larger than the upper mandible, which is not really the case.

"The calcareous extremities of both mandibles are of a hardness apparently adequate to break through the densest crustacean

[1] R. Owen, Memoir on the Pearly Nautilus (*Nautilus pompilius*), 1832, pp. 20 *et seqq*.

coverings, or even shells of moderate thickness. That of the upper mandible is sharp-pointed, and solid to the extent of five lines from the extremity; but in the lower one the calcareous matter is deposited on both sides of a thin layer of the black horny substance and thus a combination of tough with dense matter is obtained, which much diminishes the liability to fracture. This mandible is also more hooked than the upper one, but is more obtuse at the end; it seems from its dentated margin evidently intended to break through hard substances, whilst the sharp edges of the beak of the Cuttle-fish better adapt it for cutting and lacerating the soft bodies of fish. Indeed, in the particulars just mentioned, the mandibles of *Nautilus* differ from those of every other known species of recent Cephalopoda."

When found fossilised, usually only the calcareous extremities are preserved, although occasionally portions of the horny substance are found associated with them.[1]

The present fossil is represented of the natural size in the accompanying figures, and a comparison of them with corresponding figures of the upper mandible of the recent *Nautilus pompilius* at once reveals the true nature of the fossil; thus, Fig. 2*b* corresponds to the tip of Fig. 1*c*, and Fig. 2*c* corresponds to the uppermost portion of Fig. 1*d*.

A series of papers on the mandibles of Fossil Cephalopoda has comparatively recently been published by Dr. Alfred Till,[2] but the present specimen appears to differ from all the forms belonging to *Nautilus*-like Cephalopods that have already been described and is therefore regarded as new. Following Dr. Till's system of nomenclature the specimen may be named *Nautilus* (*Rhyncholithes butleri*, n.sp.) *sp.*, signifying that the name of the mandible is *Rhyncholithes butleri* and that it belonged to a *Nautilus*-like Cephalopod of which the species has not been determined.

The present fossil consists almost exclusively of the fossilised calcareous portion of an upper mandible, but it is much larger than any other specimen in the British Museum collection. It bears some remnants of the horny substance of the mandible. In the recent *Nautilus pompilius* (see Fig. 1*c*, *d*) the calcareous portion of the upper mandible consists of a hood-shaped upper portion supported below by a 'shaft'. On the inner side the surfaces of these two portions are continuous and more or less in the same plane, but on

[1] See A. H. Foord, Cat. Foss. Ceph., Brit. Mus., pt. 2, 1891, fig. 79*a* (p. 368) and figs. 80*b*, *c* (p. 369).

[2] Till (Alfred), "Die Cephalopodengebisse aus dem schlesischen Neokom": Jahrb. d. k.k. geol. Reichsanst., Wien, Bd. lvi, 1906, pp. 89–154, pls. iv, v, text-illust.

Till (Alfred), "Die fossilen Cephalopodengebisse": Jahrb. d. k.k. geol. Reichsanst., Wien, Bd. lvii, 1907, pp. 535–682, pls. xii, xiii, text-illust.

Till (Alfred), "Die fossilen Cephalopodengebisse": Jahrb. d. k.k. geol. Reichsanst., Wien, Bd. lviii, 1908, pp. 573–608, pls. xix (i), xx (ii), text-illust.

Till (Alfred), "Die fossilen Cephalopodengebisse": Jahrb. d. k.k. geol. Reichsanst., Wien, Bd. lix, 1909, pp. 407–26, pl. xiii, text-illust.

Till (Alfred), "Über einige neue Rhyncholithen": Verhandl. d. k.k. geol. Reichsanst., Wien, 1911, pp. 360–5, text-illust.

the outer side the median line of the surface of the 'hood' makes a more or less obtuse angle with that of the surface of the 'shaft'. The measurements of the detached calcareous portion of the upper mandible of a recent *Nautilus pompilius* figured by Dr. Till (1906, pl. iv, figs. 1, 2, 3) are: total length, 14·5 mm.; breadth, 10·1 mm.; length of hood (measured along median line of outer side), 10·5 mm.; length of shaft (measured along median line of outer side), 8·5 mm.; angle between the hood and the shaft (measured along the median line of the outer side), 98°. The angle of the apex of the hood as seen from the inner side is 82°.

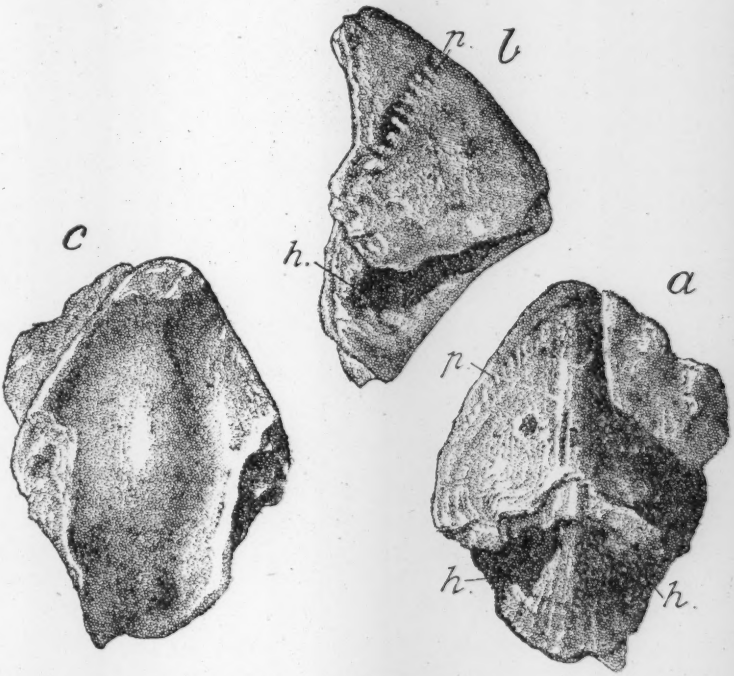

FIG. 2.—*Nautilus* (*Rhyncholithes butleri*, n.sp.) *sp.* The type-specimen. *a*, outer aspect showing the obtuse ridge along the median line of the hood and at *h* remains of the chitinous portion of the mandible; *b*, lateral aspect, showing at *p* a series of shallow pits caused perhaps by a fringed lip, and at *h* remains of the chitinous portion of the mandible; *c*, inner view showing the median protuberance. Natural size. Most probably from the Inferior Oolite of Bradford Abbas (Dorset) or of the immediate neighbourhood. Original in British Museum (Nat. Hist.), London, Geol. Dept., No. C. 18659.

The present specimen is incomplete both at the apex and at the hinder end, so that only approximate measurements are possible. They are: extreme length, 51·7 mm.; breadth, 35·6 mm.; length of hood (measured along the median line of the outer surface), 38·6 mm.; length of shaft (measured along the median line of the outer

surface), 33·2 mm. Viewed laterally the median line of the hood is feebly convex; that of the shaft feebly concave, especially the portion near the hood. The 'profile-curvature' angle, or the angle which the median line of the 'hood' makes with the median line of the 'shaft', is 94°. The hood has a prominent obtuse median ridge, the sides of the hood forming an angle of 109° with each other. Near the anterior and inner border there is a series of longitudinally-elongated pits, closed anteriorly but open posteriorly, that may perhaps have been caused by a fringed lip such as was described by Sir Richard Owen in the recent *Nautilus pompilius*,[1] and on the posterior portion of the hood there are some coarse obscure longitudinal ridges. The outer surface of the shaft bears both longitudinal and transverse feeble rounded ridges, giving the surface an obscurely reticulated appearance. On each side of the shaft close to the hood there are remains of the chitinous portion (marked *h* in figs. 2*a* and *b*) of the mandible. Viewed laterally the inner surface of the mandible is feebly sigmoidal, the anterior portion being concave and the posterior part convex. The anterior two-thirds of this surface is occupied by a protuberance which is widest at its posterior part, being there about 10 or 11 mm. wide, and anteriorly narrows and also becomes much less prominent. The hindermost part of the inner surface has several deep irregular depressions. The angle of the hood as seen from the inner side is 61°.

As to the affinities of the fossil, it most nearly resembles the specimen which d'Orbigny[2] described and figured in 1825 from the Corallian rocks of the Chez promontory, near La Rochelle, France, under the name of *Rhyncholithes giganteus*, and which was found in the same bed as a large Nautilus, which he named *Nautilus giganteus*, that attained a diameter of 18 or 19 inches and was the only Cephalopod found in the bed which yielded the mandible. According to d'Orbigny's figures that specimen was longer and narrower than the present example; its extreme length and breadth being 54·8 mm. and 31·2 mm. respectively, the angle at its apex, as seen from the inner side, being 48°; also the swelling on its inner surface extends farther backward than in the present example.

We are then led to ask if any Inferior Oolite *Nautilus* is known sufficiently large to have owned such a mandible. Dr. Foord and the present writer described[3] in 1890, under the name *Nautilus ornatus*, a species of *Nautilus* from the Inferior Oolite that attained a considerable size, for the British Museum collection contains an example[4] [No. C. 578] of the species 16 inches in diameter from a quarry near Oborne Church, near Sherborne, Dorset, and another 2 feet in diameter from the Inferior Oolite of Sherborne [No. C. 3193]. The mandible above described might then have belonged to a large example of such a species.

[1] R. Owen, *op. cit.*, p. 22. A somewhat similar series of pits is figured by Foord (Cat. Foss. Ceph. Brit. Mus., pt. 2, 1891, figs. 78*d*, *e*, *f*) in an upper mandible from the Lias of Lyme Regis, that Dr. Till has subsequently (Jahrb. d. k.k. geol. Reichsanst., Wien, Bd. lvii (1907), Hft. 3, p. 539) named *Nautilus* (*Rhyncholithes punctatus*) *nom. nov.*

[2] A. d'Orbigny, Ann. Sci. nat., tom. v, 1825, pp. 215–17, pl. vi, fig. 1.

[3] Ann. Mag. Nat. Hist., [6], vol. v, p. 273, fig. 7.

[4] Presented by George Potter, Esq., F.R.M.S.

VI.—Radio-activity and the Earth's Thermal History.

By Arthur Holmes, A.R.C.S., D.I.C., B.Sc., F.G.S.

PART III.[1]

Radio-activity and Isostasy.

14. Isostatic Compensation.

THE distribution of land and sea implies that the earth's outer shell is in a condition of approximate hydrostatic equilibrium. Otherwise the equatorial regions should be girdled by a continental protrusion, or else each of the polar regions should be occupied by a continental bulge.[2] The observed fact that the inequalities of the earth's surface exhibit neither of these conditions proves that the general ellipticity of the lithosphere does not differ greatly from that which would be assumed by a liquid spheroid having a similar distribution of density in depth. The incapacity—thus demonstrated—of the lithosphere to endure permanent stresses leads naturally to an inquiry into the conditions that maintain continents and mountain ranges above sea-level. Investigations based on the deviations of the plumb-line from the vertical and on the varying intensity of gravity indicate beyond doubt that the elevated tracts of the globe owe their support to a deficiency of density in their deep-seated foundations, while the great sunken areas owe their depression to a corresponding excess of density in the underlying rocks. Thus has arisen the conception of *isostasy*, a word which was coined by Dutton[3] in 1889 to express the state of hydrostatic[4] balance that maintains in position elevated and depressed columns of the lithosphere. Columns of equal cross-sectional area, though of different heights, may have the same mass on account of their respective densities, and if so, at a certain level beneath the mean surface of the geoid, each one will exert the same pressure on the zone below.

The regional perfection of isostasy, and its local limitations, have been demonstrated by the geodetic observations of nearly seventy years. Petit,[5] in 1849, found that the Pyrenees deflected the vertical much less than was to be expected. Archdeacon Pratt,[6] in 1852, discovered a similar anomaly in the case of the Himalayas; and during the later months of the same year Airy,[7] then Astronomer Royal, propounded a theory of compensation explaining the anomalies in terms of underlying density. Putnam and Gilbert[8] established a considerable degree of isostatic equilibrium for the United States in 1895, and their conclusions have been verified in still greater detail

[1] Parts I and II appeared in the Geol. Mag. for February and March, 1915, pp. 60-71, 102-12.

[2] H. Jeffreys, "The Mechanical Properties of the Earth": The Observatory, 491, p. 348, 1915.

[3] Bull. Phil. Soc. Wash., xi, p. 53, 1889.

[4] Or hydrodynamic?

[5] C.R., vol. xxix, p. 730, 1849.

[6] Phil. Trans. Roy. Soc., vol. cxlv, 1885.

[7] Ibid.

[8] Bull. Phil. Soc. Wash., xiii, p. 31, 1895.

by the laborious studies of Hayford and Bowie.[1] In India,[2] along the margins of the continents[3] and over the ocean basins,[4] a similar but less intimate association between terrestrial relief and underlying density has been recognized. At least for the broader features of the earth's topography the theory of isostasy may therefore be regarded as established.[5]

15. Limits of Isostatic Equilibrium.

Hayford and Bowie, in their analysis of the results of the U.S. Geodetic Survey, found that by introducing the conception of isostatic compensation they were able to reduce deflection anomalies and gravity anomalies to respectively one-tenth and one-quarter of the value these anomalies would have had without applying the compensation hypothesis.

The depth of compensation which most successfully reduces the anomalies is 122 km., though it should be noticed that the depth chosen may range from 66 to 305 km. and yet give an almost equally good reduction. Hayford suggests that "the maximum horizontal extent which a topographic feature may have and still escape compensation is between one square mile and one square degree" (op. cit., 1906, p. 169). This conclusion implies that the earth's crust is so weak that the weight of accumulating sediments on the sea floor may well cause the latter to sink. Barrell, however, has made a careful study of the Nile and Niger deltas, and deduces from their thickness and great areal extent a much stronger crust than is possible on Hayford's view of local compensation. Moreover, he demonstrates that the geodetic results of the United States, "instead of indicating local compensation to limits of less than one square degree, show on the contrary a ready capacity of the crust under the United States to carry over areas of from 5 to 10 or 15 square degrees, and exceptionally over even larger areas, departures from equilibrium greater than the mean" (op. cit., 1914, p. 165). Barrell supports his view of a strong crust by citing the immense departures from isostatic equilibrium exhibited by areas in India, Japan, and Norway, by the great basaltic dome of Mauna Kea, and by the Tonga Plateau and Deep. That the strength so manifested is greater than that of the surface rocks is only to be expected, for the experiments of Adams have proved beyond question that granite, for example, becomes increasingly stronger with increase of pressure.[6] There can be no doubt that North America is at present in a state of much

[1] Hayford, Proc. Wash. Acad. Sci., vol. viii, p. 25, 1906; U.S. Coast and Geodetic Survey, 1909 and 1910; Science, vol. xxxiii, p. 199, 1911. Hayford and Bowie, U.S. Coast and Geodetic Survey, 1912, Spec. Pub. 10. Bowie, U.S. Coast and Geodetic Survey, 1912, Spec. Pub. 12; *Am. Journ. Sci.*, vol. xxxiii, p. 237, 1912.

[2] Burrard, Survey of India, 1912, Prof. Paper 12; Crosthwait, Survey of India, 1912, Prof. Pap. 13.

[3] Schiötz, Skrift. Vedensk. Selsk. Christiania, 1908, No. 6.

[4] Hecker, Veröff. k. Preuss. geodät. Inst. Berlin, 1903, No. 11; 1908, No. 12. See also Bauer, *Am. Journ. Sci.*, vol. xxxi, p. 1, 1911; vol. xxxiii, p. 245, 1912.

[5] Gilbert, U.S.G.S., 1913. Prof. Pap. 85-C. Barrell, *Journ. Geol.*, vol. xxii, Nos. 1-8, 1914; vol. xxiii, Nos. 1, 5, and 6, 1915.

[6] *Journ. Geol.*, vol. xx, p. 97, 1912.

more perfect isostatic equilibrium than are most areas of the earth's surface, and the evidence it affords of the strength of the earth's crust is therefore insufficient and inconclusive. Barrell justly concludes that "Isostasy . . . is nearly perfect, or is very imperfect, or even non-existent, according to the size and relief of the area considered". For the continents and oceans the degree of adjustment is high; within areas of 250 km. in diameter the departure from equilibrium may be high; while individual peaks and even small ranges may be wholly supported by the rigidity of the underlying rocks.

16. The Asthenosphere.

Barrell has shown that the greater departures from isostasy impose very considerable stress differences on the zone of compensation, and he has applied this fact to a deduction of the strength of the lithosphere at various depths. If a series of wave-like curves represent the profile of uncompensated hills and valleys, or of oceanic islands and troughs, then the maximum stress difference is imposed at a depth of $1/2\pi$ of the wave length. In various parts of the world such wave lengths can be approximately measured. For example, in the ridges and troughs of the Pacific the wave lengths are from 300 to 500 km. Even if the strains set up by these loads were entirely unmitigated by compensation, the maximum stresses would not be applied at depths greater than 80 km. That is to say, the existing inequalities which lack complete compensation are responsible for loads that are almost wholly borne by the zone of compensation as defined by Hayford. Greater inequalities of topography would, if uncompensated, throw stress differences to correspondingly greater depths, and the fact that such inequalities do not exist unless they are largely or wholly compensated implies that the rocks below the zone of compensation are too weak to support them. Otherwise, if the rocks were rigid enough to support great mountain ranges, why should the latter be compensated at all? It is a natural conclusion that the lithosphere (limited at its base by the bottom of the zone of compensation) is strong, especially in its upper half, compared with the underlying zone. For the latter Barrell proposes the name *asthenosphere*—sphere of weakness. The evidence he brings forward leads him to suggest the following approximate figures, to illustrate the variation of strength with depth (op. cit., 1915, p. 44):—

	Depth in kilometres.	Strength in percentage.
Lithosphere	0	100[1]
	20	400
	25	500
	30	400
	50	25
	100	17
Asthenosphere	200	8
	300	5
	400	4

The relative weakness and plasticity of the asthenosphere is capable of a second proof based on the implications of isostasy. Denudation

[1] At the surface strong limestone or granite can sustain a stress difference of 25,000 pounds per square inch (1,750 kg. per sq. cm.).

involves a paring away of the upper surface of the lands, and an accumulation of the resulting debris around their borders. The land columns become lighter; the sea floor is weighed down. An equally certain fact, attested by many an eloquent chapter of geological history, is that during the transfer of load from continent to ocean floor the former rises and the latter sinks. What is the hidden mechanism that restores the isostatic balance? Corresponding to the lateral movement of sediment there must be a lateral counter-movement in the rocks far below. At first Hayford considered that this undertow took place *within* the zone of compensation, but Barrell[1] has convincingly shown that this view is untenable, and Hayford[2] in his latest pronouncement has apparently abandoned it. The undertow must be *below* the zone of compensation, and consequently the matter at greater depths must be somewhat plastic. Moreover, to maintain an isostatic balance between segments of the lithosphere so extensive as continents and ocean basins the plastic zone—the asthenosphere—must be very thick, certainly several hundreds of kilometres.

Quite independent evidence comes from another branch of geophysics. It has sometimes been assumed that a viscous magmatic zone might exist within the earth between a rigid crust and a rigid core. Schweydar[3] has tested this theory by analysing the results of earth-tide measurements made with the horizontal pendulum. He proved conclusively that a magmatic zone of the kind imagined could not exist, and showed that the results pointed—as one alternative—to the existence of a slightly plastic zone extending downwards from a depth of 120 km. and fading out some 600 km. below.

The existence of the asthenosphere is thus supported by arguments based on three different lines of investigation. In the remaining part of this paper its existence will be accepted, and used as a criterion by which to test the distribution of temperature within the earth that was deduced in Part II.

17. The Temperature Curve tested by Isostasy.

The temperature at any depth below the earth's surface has been regarded as the sum of three components—(1) that due to the initial temperature at or near the surface, and since modified by cooling; (2) that implied by the variation of the fusion-point with depth, as controlled by pressure; and (3) that due to the local distribution of the radio-active elements.

These three components are mathematically expressed for any depth x in equations 9 and 13 on p. 111 of Part II (March, 1915). In calculating the list of temperatures there tabulated, it was assumed that the downward increase of temperature due to pressure was 0·00005° C. per cm., or 5° C. per km. Such an assumption cannot, of course, be applied satisfactorily to any considerable depth. We do not know to what extent the law connecting pressure with a rise of the fusion-point of a mineral is linear, and moreover the distribution of minerals in depth cannot be a simple continuation of

[1] Barrell, op. cit., p. 677, 1914.
[2] Hayford, Proc. Am. Phil. Soc., vol. liv, p. 298, 1915.
[3] Veröff. Preuss. geodät. Inst., No. 54, 1912.

what is observed at the surface. If, therefore, the pressure component could be left out of the discussion altogether, and a disturbing factor thus avoided, a considerable advantage would be gained. Now, for the present purpose, this can readily be done, for it is required to compare the fusion-points of certain minerals and rocks [1] with the temperatures at depths appropriate to their occurrence within the earth. Let us suppose that for a given mineral or rock the rise of the fusion-point at a depth x is mx. Then the pressure component of temperature at that depth will also be mx. The fusion-point may be expressed as $S + mx$ where S is the fusion-point at the surface, and the temperature as $T + mx$ where T is the temperature due to other factors than the pressure component. Consequently, in plotting fusion-point and temperature curves the differential relation of one to the other will not be affected by plotting S and T respectively instead of $S + mx$ and $T + mx$. Thus, at every depth, x, the appropriate but at present unknown value of mx, may be omitted without detriment, and with the advantage that a doubtful extrapolation is completely avoided.

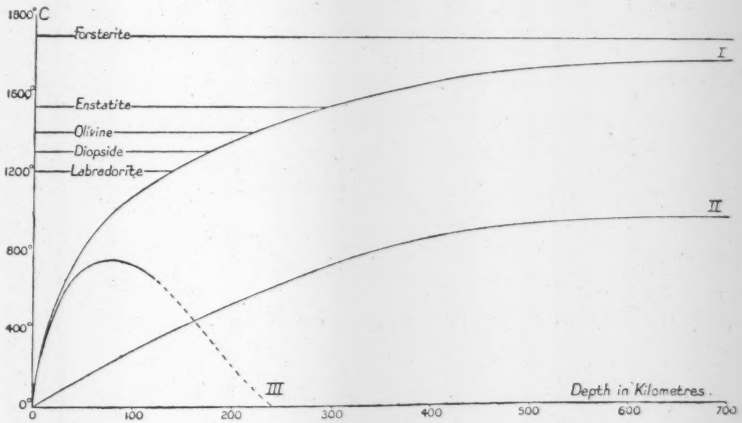

FIG. 1.—The distribution of temperature in depth in relation to the fusion-points of minerals.

I. Temperature gradient due to radio-activity and the earth's initial thermal condition in the respective ratio of 3 : 1.

II. Temperature gradient due to the earth's initial thermal condition alone.

III. Temperature gradient due to radio-activity alone.

In each case the pressure component mx is omitted.

In the adjoining diagram the temperature T is plotted in degrees Centigrade against depth in kilometres. Curve I represents the distribution of temperature based on the discussion in Part II (omitting the pressure component mx); that is to say, the temperature gradient is considered on an average to be due to radio-activity and secular cooling in the ratio of approximately 3 to 1. Curve II

[1] By the expression "fusion-point of a rock" is meant the minimum temperature at which the whole of the rock passes into the non-crystalline condition.

represents the distribution of temperature in an earth which has cooled down for 1,600 million years from an initial temperature at or near the surface of 1,000° C. Curve III represents the distribution of temperature due to radio-active elements alone, and here mx is subtracted from the value at every depth x on the assumption that m is 5° per km., in order that the curves may be comparable. The maximum temperature due to radio-activity could not, on an average, exceed 800° C. + mx.

Since the pressure component is omitted, the fusion curves of minerals become straight lines parallel to the base, i.e. having for every depth the same ordinates. The point of intersection of, say, the labradorite line with any of the temperature curves gives the depth at which labradorite would fuse. Clearly, if none of the earth's heat were due to radio-activity (curve II), or if all its heat were due to radio-activity (curve III), none of the minerals represented in the diagram could fuse at all, whatever the depth. The temperature at which basalt fuses cannot be safely put below 1,200° C., and hence basalt magma, and for a similar reason peridotite magma, could not be produced under the conditions of curves II and III. Volcanic phenomena therefore bear witness to the verity of some such curve as I, and indeed curve I expresses almost the maximum temperatures that can occur in depth over wide areas and yet avoid the impossible extremes of universal vulcanism and no vulcanism.

Curve I implies that basalt magma cannot usually be produced at a depth of less than 140 km. But can basalt be supposed to exist at all at such a depth? The distribution of the radio-active elements indicates that it cannot. Indeed, even at a depth of 40 km.[1] basalt —or whatever may there be its equivalent—could not hold as much uranium and thorium as the basalts which have reached the surface, for if it did so the temperature gradient would certainly be higher than it is. The great majority of the basaltic material of the earth seems, in fact, to be confined to an outer shell of about 30 km. in thickness. Below that depth, the peridotite minerals cannot hope to find a temperature at which they could melt within 200 or 300 km. of the surface. Beyond depths of this order peridotite may begin to approach its melting-point, and thus to attain the possibility of plastic flowage, but it is clear from curve I that actual fusion is not likely anywhere to be a widespread condition. If at any time fusion did become possible the fluid material would be squeezed out to higher levels, leaving a concentration of the unfused materials. It is therefore to be expected that the more fusible ferriferous olivines have long ago been expelled from the interior, leaving behind varieties richer in magnesium, accompanied perhaps by such refractory accessories as chromite. This view is strongly supported by the fact that ferriferous olivines are, on an average, richer in radium than those in which the forsterite molecule predominates. As between hypersthene and enstatite the same rule holds.

Barrell's views as to the physical condition of the asthenosphere are therefore seen to be completely in accord with the temperature

[1] 70 km. would be the maximum depth possible if the continents were not capped with granites.

distribution expressed in curve I. The weakest part of the outer regions of the earth must be located *below* the zone of compensation, and this conclusion may be used as an additional argument in favour of the existence of an asthenosphere, or, accepting the asthenosphere, it may be used as a rough corroboration of the distribution of temperature here advocated.

18. Vulcanism in relation to Mountain-building and Rigefaction.

It may be thought that the preceding discussion leads on to the deduction that, whatever vulcanism may have gone on in the past, none ought to be possible at the present day. This is not so, for until now an *average* distribution of the radio-active elements has alone been considered. In relation to worldwide phenomena such as the maintenance of isostasy between continents and oceans, the use of average conditions is justified by the broadness of the problems involved. In relation to more localized phenomena such as mountain-building, block faulting, and vulcanism, departures from average conditions become critically important. The departures may, of course, be of two kinds, those in which the distribution of the radio-active elements and the dependent temperatures in depth are locally in excess of the average, and those in which the radio-active elements and deep-seated temperatures are deficient.

Let us consider the first of these cases. In regions of heavy sedimentation, a thick blanket of rocks considerably richer in radium and thorium than basalt (Part I, p. 63, February, 1915) is superimposed on the previously existing "radio-active layer". As Professor Joly has shown, when "we take into account that in the radium content of the sediments there is a source of heat competent to bring the geotherms closer to the surface in the region of deposition than elsewhere in the surrounding crust",[1] the possibility of weakness and even of fusion at moderate depths becomes clear. The rise of temperature at and below the base of the accumulating sediments is much greater than one would think possible, for the basal temperature due to radio-activity is proportional to the square of the thickness of the uniform radio-active layer above it. To illustrate the effect by a concrete example, let us take the figures referring to average igneous rock given on pp. 66 and 67 of Part I (February, 1915). If the distribution of radio-activity were uniform the depth of the radio-active layer would be 30 km., and the basal temperature 570° C. The addition of a thickness of 10 km. of sedimentary rock would then increase the thickness of the radio-active layer to 40 km. and the new basal temperature would become 1,005° C. ($30^2 : 40^2 = 570 : 1005$). Since the distribution of radio-activity is not uniform, but decreases in depth, and therefore continues to much greater depths than 30 km., so the rise of temperature due to sedimentation is considerably greater than that given in the calculation just made. An exact calculation of the effect on an exponential distribution would be difficult, if not impossible, but the magnitude of the rise in temperature may be appreciated by considering only the outer 10 km.

[1] *Radio-activity and Geology*, 1909, p. 94; see also *The Birth-time of the World*, 1915, p. 116 et seq.

shell. Normally its temperature due to radio-activity is 264° C. (p. 111, Part II, March, 1915). The addition of a 10 km. blanket of sediment would increase this temperature, now at a depth of 20 km., to over 1,000° C. ($10^2 : 20^2 = 264 : 1056$). The association of volcanic eruptions with sedimentation and the weakening of the crust preparatory to the upheaval of mountains along lines of heavy sedimentation thus becomes easily explicable.

The second case—that involving a deficiency of radio-activity—applies to areas which have undergone long denudation and have thus been deprived of part of their most richly radio-active rocks. If isostasy also comes into play, then regions originally at a considerable depth and temperature may become exposed at the surface. Combined cooling and uplifting gives a double reason for the development of tensional stresses. Thus areas like Africa are rigefied and strengthened by cooling, and rent asunder by contraction and uplift. The existence of structural features such as rift valleys implies the development of tension clefts reaching down to considerable depths. This in turn implies local relief of pressure and a corresponding reduction of the temperature at which the rocks below can attain fusion. Here, then, although the surface phenomenon is one of cooling and rigefaction, the effect in depth is to promote fusion, and vulcanism is again made possible. It thus appears that igneous activity may be controlled by two totally different classes of phenomena; in some regions by radio-active superheating, and in others by far-reaching relief of pressure. It is to be expected, then, that the mechanism of intrusion should be notably different in the two cases, and that at least partial differences in the composition of the resulting rocks should be observed between them. We have here a physical explanation for the undoubted core of truth contained in the conception of 'Atlantic' and 'Pacific' types of igneous rock—a conception that errs in detail rather than in principle, and one that has suffered by the rigidity of its expression rather than by its lack of verity. It is hoped in later contributions to this series of articles to discuss earth movements and their appropriate igneous associations in the light of the considerations briefly outlined above.

19. Isostasy and the Age of the Earth.

The title of this article provides the author with a suitable opportunity for discussing a recent paper by Dr. G. F. Becker.[1] In it Dr. Becker correlates recent developments in isostasy with others arising from the application of radio-activity to geological problems. He assumes that the undertow by which isostasy is maintained takes place at the basal level of isostatic compensation (i.e. at the depth of, say, 121 km.), and that this level must also be the "eutectic level" at which fusion can most easily be accomplished. The "eutectic level" x_1 is calculated from the following equation connecting x_1 and t, the age of the cooling earth :—

$$\frac{h\sqrt{\pi t}\,(V-b)}{0{\cdot}01\,r\,V} = e^{-x_1^2/4h^2t} \qquad (14)$$

[1] "Isostasy and Radio-activity": Bull. Geol. Soc. Am., vol. xxvi, pp. 171–204, 1915.

The symbols are those employed in Part II (p. 108) except that V is the initial surface temperature of the earth, taken by Becker as 1,300° C., and b is the melting-point of diabase at the surface, taken on the authority of Barus as 1,170° C. Solving with Becker's data and giving definite values to x_1, the following are some of the results obtained:—

x_1, the depth of easiest fusion, in km.	The proportion of the temperature gradient maintained by radio-activity.	t, the age of the earth in years.
121	0·1425	68 million.
180	0·43	200 ,,
254	0·59	600 ,,
300	0·6667	1,314 ,,
315	0·675	1,600 ,,

If x_1 is actually the depth of the level of isostatic compensation, as Becker believes, then the age of the earth is 68 million years according to this calculation, and only one-seventh of the earth's heat can be maintained by radio-activity. The impossibility of the latter result itself throws doubt, if indeed it does not disprove, the validity of the whole method. Curiously enough, however, the calculations show that if the level at which isostatic restoration most readily takes place is at a greater depth than 300 km., then the age is either about that required by radio-active minerals or is considerably higher. The work of Barrell on the strength of the earth's crust, and of Schweydar on tides in the solid earth, suggest that the depth of flowage in question actually is greater than 300 km., and the quite independent results of this paper are in complete accord with such a conclusion. So far from disproving the great age of the earth implied by radio-active methods, Becker's analysis would seem to lead to an equally high or even higher age. But it may be noticed that the value of t derived from any stated value of x_1 in equation 14 is strongly affected by the value of $V-b$. Thus the results are vitiated at their very source, for the figure chosen for V, viz. 1,300° C., is a pure guess. Any other figure would give totally different values for t. Moreover, the equation fails altogether to give a rational result if $(V-b)$ is not positive; that is to say, unless the initial surface temperature of the earth were higher than the melting-point of whatever rocks are in place within the asthenosphere. Already Becker's paper has been quoted as furnishing an argument against the radio-active methods of determining time. Clearly it fails to do so for the following reasons:—

(1) The value assigned to V is a pure guess.

(2) The depth of the "eutectic level" is said to be at the level of isostatic compensation instead of 200–300 km. *below* that level.

(3) The proportion of the temperature gradient maintained by radio-activity cannot, on the age favoured by Becker, be more than one-seventh of the whole.

(4) It is assumed that 'diabase' can be present at a depth of 121 km.

(5) If the method were valid it would imply that the earth had cooled for considerably longer than 1,600 million years.

20. Conclusions of Part III.

1. Barrell's investigation of the strength of the earth's crust, based on geological, geodetic, and geophysical data, indicates that the depth of maximum flowage by which regional isostasy is maintained lies within the asthenosphere at a depth far below Hayford's level of compensation.

2. The distribution of temperature in depth (due partly to radio-thermal energy and partly to the initial thermal state of the earth) deduced in Part II is fully in accordance with the mechanical status ascribed to the asthenosphere.

3. Mountain-building and associated igneous activity are localized by the radio-active blanket of deep sedimentation.

4. Rigefaction and tensional faulting and associated igneous activity are localized by denudation and relief of pressure.

5. Becker's latest method of calculating the age of the earth is invalid, and, if it were not, would lead to a figure for the age of the earth as great as that suggested by lead-uranium ratios, or to one even greater.

REVIEWS.

I.—Memoirs of the Geological Survey.

The Geology of the South Wales Coalfield. Part XII: The Country around Milford, being an account of the region comprised in Sheet 227 of the Map. By T. C. Cantrill, B.Sc., F.G.S., E. E. L. Dixon, B.Sc., F.G.S., H. H. Thomas, M.A., Sc.D., F.G.S., and O. T. Jones, M.A., D.Sc., F.G.S. pp. vii, 185. 1916. Price 2*s.* 6*d.*

IN the Magazine for 1915 (p. 171) a notice of the memoir explanatory to the sheet east of the present one appeared. The general character of the geology of the area described in the present memoir is similar to that in the preceding one, but there are differences, some of which are of special interest.

The Pre-Cambrian rocks of the Haverfordwest region are continued into that of Milford, and are there representative of the same two groups, the Johnston plutonic series and the Benton volcanic series. The latter is rich in soda rocks; the former is suspected to be intrusive into the latter. A gneissose structure occurs in some of the Johnston rocks, and as these are thrust over Lower Carboniferous rocks which exhibit foliation as the result of the thrust, it might be suspected that the gneissose structure was also produced by that thrust, but the field evidence is against this view, and suggests an earlier period for the production of the gneissose structure. Cambrian sediments of Lingula Flag age are found as in the area to the east, and the general succession of the sedimentary Ordovician rocks in the two regions is similar, and therefore requires no further notice.

An interesting feature in the area under consideration is the marked development of Ordovician volcanic rocks, one certainly and the other probably of Arenig age. These are the rocks of the Trefgarn and Skomer volcanic series. The Trefgarn Series is developed about

Roch, and consists of keratophyres and other rocks. The remarkable beds of the Skomer Series were described by Dr. H. H. Thomas in 1911 (Quart. Journ. Geol. Soc., vol. lxvii, p. 175), but further details are given in this memoir. They vary from rhyolites to olivine basalts, and are interesting on account of the abundance of rocks rich in soda. They are best developed in Skomer Island, but their relationship with other rocks is seen on the adjoining mainland, where they are overlain by Upper Llandovery beds, which by a curious coincidence also contain contemporaneous volcanic rocks.

Of Silurian rocks, the Lower Llandovery beds are similar to those in the eastern region, but not so well developed. The Upper Llandovery beds contain the above-mentioned volcanic rocks of a basaltic character and showing 'pillow' structure. In one locality certain beds may be referable to the Tarannon stage, but in parts of the area, at any rate, there is a marked overstep at the base of the Wenlock.

A full description of the Wenlock–Ludlow succession is given, and it is of importance, inasmuch as these beds have a different facies from that of those of the typical Silurian area, being marked by much arenaceous material and an absence of important limestone bands and of graptolitic shales. The presence of *Stricklandinia lirata* and *Pentamerus globosus* in Wenlock strata indicates that these forms must be regarded as facies-fossils and not as zone-fossils.

The Old Red Sandstone strata are found on both sides of Milford Haven, and are in many respects similar to those of the Haverfordwest region, being divisible into Lower Old Red Sandstone, consisting of conglomerates, sandstones, and marls, and Upper Old Red Sandstone (the Skrinkle Sandstones), composed of sandstones, marls, and limestones.

The junction of the Lower Old Red Sandstone with the Silurian rocks is seen to the north of the Haven. At St. Ishmael's and Marloes Bay the base of the Old Red conforms with the top of the Silurian, as seen at the Red Cliff and near Gateholm. "There is no reason to think that there is any non-sequence." One might have hoped that the important *Eurypterus remipes* fauna would have been discovered here: it may yet be found.

Particularly interesting is the succession of strata at the top of the Upper Devonian rocks. The Skrinkle Sandstones consist of beds of 'continental facies' interbedded with "grey sandstones, mudstones, and limestones, with an Upper Devonian fauna ('marine facies')". So far back as 1868 the late J. W. Salter maintained, on account of the presence of *Curtonotus* and other fossils at West Angle Bay, that marine beds of Devonian age occurred there (Quart. Journ. Geol. Soc., vol. xix, p. 480). The list of fossils given in the present memoir fully confirms his conclusion. A further account of these important rocks is promised when the Pembroke and Tenby Memoir appears. As these beds are succeeded by Carboniferous rocks of the *Cleistopora* zone, it would seem that here at last we have the longed-for evidence as to the line of demarcation between the Carboniferous and marine Devonian rocks of Britain, with all the light which it will throw upon the 'Devonian question'.

Passing to the Carboniferous rocks, we find the Carboniferous Limestone division also developed on the two sides of Milford Haven. To the north there is a limited development at Goultrop Roads, which is of interest from the point of view of tectonics. On the south side the Lower Limestone Shales (*Cleistopora* zone) are succeeded by the Main Limestone, of which the lowest part only (*Zaphrentis* zone) is developed. The Millstone Grit oversteps the underlying rocks. As in the Haverfordwest area, it is separable into three divisions.

The Coal-measures have a thickness of about 6,200 feet. The coals are anthracitic. At the time of the recent survey only one small windlass pit was at work, and the coal industry in the district seems "to have reached its zenith about the latter half of the eighteenth century". The fossil floras indicate that the Coal-measures here belong to the Middle (Westphalian) division.

A very interesting chapter treats of the Tectonics. One set of movements with lines of Caledonian trend is dominant in the north of the region, and affects rocks up to and including the Silurian strata, though movements occurring after the formation of the Lower Old Red Sandstone, and probably in the interval between its deposit and that of the Upper Old Red, have lines of Armorican trend, due possibly to pressure against a Pre-Cambrian ridge. The Post-Carboniferous movements are dominant in the south. Some lines have a Caledonian direction, but the principal have an Armorican trend.

Details are given of the interesting structures developed by the various movements. The most striking feature is the overthrust of Pre-Cambrian rocks over Carboniferous Limestone as seen in Goultrop Roads, accompanied, as before stated, by schistosity in the later rocks. This limestone had been observed by De la Beche before the middle of the last century. An excellent photograph of the section is given in plate iv of the present memoir.

The superficial deposits are described in ch. xiv. The South Welsh raised beach has been detected on Milford Haven and in Skokholm Island. As in the area to the east, there is evidence that the ice came from the north-west. Several far-travelled boulders, many apparently of Scottish origin, are found in the drifts. These drifts indicate that the glaciation extended to the south of Milford Haven. In Druidston Haven the Boulder-clay contains marine shells, some of which are characteristically Arctic.

The economic products are described in ch. xv.

The memoir is illustrated by thirty text-figures, maps, etc., and seven plates reproduced from photographs. The maps will be of special use at present, as the colour-printed 1 inch map of which the memoir is descriptive is not yet published.

To the general geologist the district is perhaps even more interesting than that to the east, and the Skomer volcanic rocks, the marine Devonian sediments of Milford Haven, and the overthrust of Pre-Cambrian over Carboniferous rocks in Goultrop Roads are especially noteworthy. Furthermore, as will be seen from an inspection of the photographs, the coast scenery is of a very high character, and those who love to combine study of geology with appreciation of scenery will not regret a visit to the district. To make this successful it will

be necessary that they should go there with the memoir in pocket as a guide. J. E. M.

II.—The Mesozoic and Cenozoic Echinodermata of the United States. By W. B. Clark and M. W. Twitchell. Washington, U.S. Geological Survey, vol. liv, 1915. 4to. pp. 3401, with 108 plates.

THE marine Mesozoic fauna of North America has hitherto lacked detailed description in many directions. This is in part due to the relatively poor development of marine deposits of that stage (and in particular of the Jurassic), and in part to the consequent superior interest attaching to the Palæozoic and Land Vertebrate faunas. The volume under review gathers under one cover the results of various more or less incidental investigations upon the Post-Palæozoic Echinoderms of the United States and adds very materially to the number of the described species.

All the orders of Echinoderms whose remains are known from the Secondary and Tertiary stages receive attention, but there are not many forms described other than Echinoids, and that order alone seems to provide types of special interest. In passing, one might protest against the application of a specific name to such obscure casts as those figured under the title of *Aspidura idahoensis* from the Lower Trias. That the five-rayed markings on the rock do represent Asteroids seems certain, but the fortunate discoverer of a perfect specimen would be totally unable to compare it with the type of this 'species'.

The proportionate numerical strength of the Echinoid faunas of the country can be gauged by the fact that 6 pages suffice for the Triassic and Jurassic species, while 55 are required for the Cretaceous and 113 for the Tertiary. In point of preservation and interest, this numerical index is equally reliable. The two Triassic species, both Cidaroids and both new, are represented by small fragments of the test. Of the eight named Jurassic forms, six are Regular Echinoids, of a strikingly European facies, and two might be anything. They are referred to *Holectypus*, and are as likely to represent that as any other organism, but to give specific names to such material as is figured is to court confusion. *Cidaris taylorensis*, a new species from the Lower Jurassic, seems, to judge from the figure, very problematical. Either it is a *Tetracidaris*, or some large-tubercled Diademoid. At any rate, the figure does not, as the authors state, show two contiguous plates of the same series.

The Cretaceous Echinoids, and particularly the Regular forms, have a surprisingly European, one might almost say British, character, nearly all the genera being common to the two countries, and the species showing no special differences from those with which European Echinologists are familiar. The Irregular forms are mostly of a littoral type, and compare equally closely with similar faunas on this side of the Atlantic. The wonderfully prolific stock of the *Hemiasters* seems to have had a flourishing colony in America, but some, at least, of the species referred to that genus cannot possibly be retained in it.

The Eocene fauna offers a contrast from the Mediterranean type in the extreme development of the Scutellidæ and the scarcity of the Clypeastridæ. In the Oligocene Scutellids and Laganids are still predominant, but a magnificent species of *Amblypygus* deserves mention. In this section a double systematic disaster has to be recorded. A fragmentary Cidaroid radiole is given a new 'specific' name, and that name is *Cidaris smithi*. Apart from the fact that such a specimen does not deserve to be the type of a species, nor even the original of a figure, the name employed is thoroughly preoccupied. Systematists who describe new species of *Cidaris* (and, alas! their number is still legion) should really be careful about the names they employ. If the patronymic of Smith had been omitted from the thousand or more of names that have followed the word *Cidaris*, there would indeed have been a marvel to record.

The Miocene and succeeding Echinoid faunas are dominated throughout by the abundance and variety of the 'Sand-dollars', and have in all respects a typically American facies.

The volume as a whole is of uniform value, and the plates, though irregular in quality, are lavish and satisfactory. But it is necessary to protest once more against the view that every specimen must have a name, and, if it is too imperfect to be identified with an established species, a new name. Moreover, the descriptions of the species, though admirably concise and intelligible, are almost devoid of references to allied forms. Comparisons, though often to be deprecated, are the most fruitful means of study in the case of a largely new and isolated fauna such as the authors have before them. As an outstanding example of this defect, it may be mentioned that the only new genus instituted is ushered in with no more ceremony than the old ones, and, save for the etymology of its name and the place in the book where it appears, there is no clear indication of the reasons for its establishment nor of its taxonomic position. Excessive brevity is a rare, but irreparable, fault. By tedious filtration the facts may be separated from a prolix account, but no amount of study will extract them from a brief paragraph into which they were never inserted.

Apart from these details, the book affords a useful summary of the present knowledge of the faunas described, and will greatly assist in further work upon them. Its most original feature occurs on the last plate, where a photograph of the *scenery* on a ranch in California is given to show the abundance and excellent preservation of the Miocene Scutellidæ. Surely it is to California that all good Echinologists go, when they leave these fields of labour for the Elysian ranches.

H. L. H.

III.—Engineering Geology. By Heinrich Ries and Thomas L. Watson. Second edition. London, Chapman & Hall, Ltd.; New York, J. Wiley & Sons, Inc. 1915. Price 17*s*.

An engineer who is at the same time a trained field geologist has a tremendous pull over his colleague whose knowledge in this respect is small. In many engineering courses geology has not been

given the prominent place it should occupy, and many a failure must be attributed to this defect; yet it is hardly possible, or indeed necessary, for the average student to be as thoroughly grounded in the subject as the geological expert. How much, or how little, stratigraphical geology is necessary is perhaps a question. More is necessary for the mining than the civil engineer, but in any case enough facts should be known to recognize when the expert should be consulted. In the book under review the authors have succeeded well in selecting and discussing those geological principles and topics which have a special bearing upon civil engineering, and in most cases have been able to illustrate their points by reference to actual occurrences in the United States.

In the first part of the book, which deals with rocks and rock-forming minerals, the igneous rocks are classified chiefly by their megascopic and microscopic characters, chemical relations being indicated only by silica percentages. A simpler and clearer classification would have been one in which the hypabyssal are separated from the plutonic rocks, on the lines followed by Harker. The classification taken from Kemp is far too complex, and more suitable to the requirements of a petrologist than an engineer.

A valuable chapter is that devoted to underground waters, which will be read with equal advantage by both geologists and engineers. The excellent water-supply papers of the United States Geological Survey have been freely drawn upon, and the results of much detailed work are here assembled in concise form applicable to this country as well as the States. Landslides, which are often of mere academic interest to the geologist, bulk largely in the eyes of the engineer, and receive adequate treatment. A useful table is given of the slopes that should be adopted in cuts of different depths to avoid sliding. In chapter viii problems of harbour and river-mouth improvement are discussed and many cases cited in illustration.

In describing glacial deposits it is shown how necessary it is that the drifts should be mapped, and records of their varying thicknesses and composition recorded whenever possible, if only from the financial point of view. The problem of dealing with glaciers actively interfering with railroad construction does not arise in the British Isles. In one case, where the Allen Glacier was found to project across the Copper River Valley in Alaska, the engineers blasted out a grade across 5½ miles of stagnant, moraine-veneered, tree-covered ice. Ice lies beneath the ties, and future melting or advance will cause trouble and repeated repairs.

Building-stones, limes, cements, clay, and road materials are next described. The importance of testing the durability of a stone is emphasized, although this quality is often relegated to the background. Too much importance can be attached to crushing strength, for in practically no case is a block of stone required to support a weight approaching anywhere near its limit of strength. It is stated that the use of basalt as a building-stone is not widespread; we may recall that it has been used with some success in this country as a facing for sea-walls.

Coal, petroleum, natural gas, and ore-deposits also receive adequate

treatment. In the case of coal the theory is proposed that the various stages between plant beds and anthracite are due to a combination of an increasing amount of pressure and the heat developed by the pressure, but this theory—as pointed out by the authors—cannot be said to be universally accepted. In this country, for example, it has been shown that the anthracites of South Wales are mainly due to original differences in composition and bear little relation to the earth-movements that have given the coalfield its structure.[1]

In the concluding chapter, on Historical Geology, we have a concise account of North American stratigraphy.

One of the chief defects of an otherwise admirable book is the small space allotted to geological maps and sections. Lack of detailed knowledge of stratigraphy we can understand, but a civil engineer should be able to interpret nearly every geological map set before him, and this would be almost impossible if he had to rely upon the scant details presented in some five pages of text. As regards geological sections, some of the authors' are badly drawn, such as figs. 97 and 98, whilst the section, fig. 116, is impossible.

B. S.

IV.—Fauna of the Batesville Sandstone of Northern Arkansas. By George H. Girty. Bulletin 593, Department of the Interior, United States Geological Survey (George Otis Smith, Director), 1915. pp. 170, pls. i–xi.

THIS is a companion work to that on the "Wewoka Formation", issued by the author a few months since, which was noticed in the Geological Magazine for 1915, p. 569, and deals similarly with Carboniferous invertebrates. The Batesville Sandstone is considered to favour a correlation with the Cypress Sandstone and the Ste. Genevieve Limestone, which belong to the later Mississippi Series of the older Carboniferous formation. The fauna is characterized by an abundance of Cephalopoda, large Pelecypods, comparatively few Brachiopoda, besides many Bryozoa. In all 128 species are described and mostly figured, as against 30 species discussed from the same beds by Professor Weller in 1898 (Trans. New York Acad. Sci., vol. xvi). These species are represented under the following groups and genera:—**Foraminifera**: *Trochammina*, *Endothyra*. **Cœlenterata**: *Zaphrentis*. **Helmintha**: *Spirorbis*. **Bryozoa**: *Batostomella*, *Lioclema*, *Tabulipora*, *Cystodictya*, *Glyptopora*, *Fenestella*, *Polypora*, *Archimedes*, *Rhopalonaria*. **Brachiopoda**: *Lingulidiscina*, *Crania*, *Schuchertella*, *Orthotetes*, *Productella*, *Productus*, *Diaphragmus*, *Camarotœchia*, *Dielasma*, *Girtyella*, *Spirifer*, *Reticularia*, *Spiriferina*, *Clyothyridinia*, *Composita*, *Eumetria*. **Pelecypoda**: *Sphenotus*, *Edmondia*, *Nucula*, *Leda*, *Yoldia*, *Sulcatipinna*, *Leptodesma*, *Conocardium*, *Caneyella*, *Myalina*, *Schizodus*, *Deltopecten*, *Myoconcha*, *Lithophagus*, *Allorisma*, *Cypricardella*. **Scaphopoda**: *Lævidentalium*. **Gastropoda**: *Lepetopsis*, *Pleurotomaria*, *Euconospira*, *Bembexia* (?),

[1] *Coals of South Wales* (Mem. Geol. Surv.), 1908; 2nd ed., 1915.

Bellerophon, Patellostium, Bucanopsis, Euphemus, Euomphalus, Naticopsis, Platyceras, Strophostylus, Loxonema. **Cephalopoda:** *Orthoceras, Protocycloceras, Solenocheilus, Goniatites, Gastrioceras, Adelphoceras, Aptychus.* **Trilobita:** *Griffithides.* **Ostracoda:** *Paraparchites, Primitia, Glyptopleura, Cytherella.*

Exception must be taken to two of the above generic determinations. The shell figured and described as *Pleurotomaria arkansana* might more accurately be referred to *Murchisonia*, while *Pleurotomaria* aff. *perhumerosa* in all probability belongs to *Scalites* of Emmons as interpreted by De Koninck and other palæontologists of Europe, which according to Eastman (Zittel's *Text-book of Palæontology*, 1913, p. 527) should be grouped in the Raphistomidæ of Ulrich and Scofield, a family with Euomphaloid and Pleurotomaroid affinities.

R. B. N.

V.—Glacial Geology of North America.

A PONDEROUS but interesting tome of 529 quarto pages, *The Pleistocene of Indiana and Michigan, and the History of the Great Lakes*, by F. Leverett and F. B. Taylor, forms Monograph 53 of the United States Geological Survey. It describes the glacial features of a district lying between the areas covered by the previous Monographs Nos. 38 and 41, and presents the latest and most detailed account of the vicissitudes of the immense glacial lakes whose shrunken remnants form even now the greatest system of fresh-water lakes in the world. Four great ice-advances from different directions are now recognized, with three well-marked interglacial stages, and many minor advances and retreats occurred within each stage. Each has left easily traceable topographic effects or deposits; but it is the last, or Wisconsin, stage of glaciation, whose deposits cover practically all the rest, which has modelled the present relief and drainage of the vast area surrounding the Great Lakes. The fluctuations of the ice border have left well-marked morainic systems, each of which is traced across country and fully described in the memoir.

The basins of the Great Lakes were once valleys with free drainage but no lakes. The drainage was obstructed by the ice-sheet in the way with which we are now familiar, thus initiating enormous lakes, the levels and margins of which fluctuated with the movements of the ice. Fortunately they left excellent beaches and unquestionable overflow channels, whereby their former extent and respective outlets have been easily determined. The broad lines of this history are now well known, but with every addition of new facts there is a sensible modification of their details. It has been found especially that the succession of changes involved in the later lake history is much more complex than formerly supposed. This monograph is printed and published regardless of expense, with a beauty and wealth of illustration that we can only sigh for on this side of the Atlantic.

G. W. T.

VI. Borings in the Tertiaries of Victoria, Australia.—The "Cainozoic Geology of the Mallee and other Victorian Bores" (Records Geol. Surv. Victoria, iii (4), 1916, pp. 327–430, pls. lxiii–lxxviii, price 1*s.* 6*d.*), by Frederick Chapman, is a report we have

awaited with some interest. It is a report that necessitated and has received great care and much laborious and tedious work. The material came from eleven borings in the Mallee district, starting 6 miles from the South Australian boundary and penetrating some 20–30 miles or more in a direct east line into Victoria. The first ten were sunk from 200 to 400 feet and the last one to 600 feet, for the special benefit of Mr. Chapman's report. Water was met with at 170–250 feet from the surface and has risen from 10 to 70 feet in the borings. Full details of each boring are given, and the results of the fauna met with are appended. The report should set at rest the vexed question of the age of these Tertiary deposits, for no trace of a Nummulite was found. The paper is illustrated by Mr. Chapman's rough but characteristic sketches of the microzoa, by photographs of the mollusca, and four sections of rock. We venture to suggest that the plates would have been improved if printed numerals had been cut up and affixed to the prepared plates, instead of their being inserted with the pen.

VII.—Brief Notices.

1. Yorkshire's Contributions to Science: with a Bibliography of Natural History Publications. By T. Sheppard. 8vo; pp. 223. London, 1916. Price 5*s.* net.

THIS is a carefully compiled account of the Academies and periodical publications belonging to Yorkshire, to which are added notes on other publications which contain matter relative to the county. It forms a sort of supplementary volume to Mr. Sheppard's recently published Bibliography of Yorkshire Geology (Proc. Yorkshire Geol. Soc.). We hope the labour expended will have its reward in a full appreciation by all Yorkshire geologists and naturalists.

2. An American Carboniferous Fauna.[1]—The fauna of the Morrow Group occurring in Oklahoma and Arkansas is critically considered by Mr. Mather and a large number of new species described. The fauna, which occurs in three limestone lenticles in about 400 feet of rocks, is of importance because the associated fossil plants fix its age as Pottsville, and it shows an interesting commingling of Mississippian and Pennsylvanian forms, which are clearly distinguished as the residual and proemial elements in the paper. The fauna is compared with others in the Western States and also with the "Bergkalkschichten" of Mjatschkowa and a similar fauna in Spitzbergen. Finally, it is compared with the Pendleside fauna. Judging from the figures given in the fifteen plates it is not improbably very similar to that of the uppermost beds of the Carboniferous Limestone in Derbyshire and Yorkshire, the zone D^2.

3. British Fossil Insects.[2]—The Lacoe Collection in the United States National Museum contains some fossil insects collected by

[1] Kirtley F. Mather, "The Fauna of the Morrow Group of Arkansas and Oklahoma": Bull. Sci. Lab. Denison University, vol. xviii, pp. 59–284, December, 1915.

[2] T. D. A. Cockerell, "British Fossil Insects": Proc. U.S. Nat. Mus., vol. xlix, pp. 469–99, pls. lx–viii, December, 1915.

P. B. Brodie from the English Lias and the Oligocene of Gurnet Bay, Isle of Wight. Cockerell describes forty-four new species from this material, bringing the total number of described British fossil insects to 368. It is unfortunate that only a few of the far larger collections from the same localities in the British Museum have been described.

4. The Occurrence of Dinosaurs in Bushmanland.[1]—These two papers record the occurrence of an Iguanodont Dinosaur in the infilling of a valley in the gneiss of Bushmanland, and give a description of the remains, which are scarcely generically determinable. The importance of the find is that it is the first direct evidence that we have obtained of the conditions of the central part of South Africa between the end of the Trias and Recent times. It is to be hoped that these bones may prove the forerunners of a whole series of land vertebrate faunas filling this great gap.

5. The Fens.[2]—In this little pamphlet Professor McKenny Hughes brings together much information of the Fenland, its origin, the peaty strata which cover it, and the marine alluvial surrounding the Wash. The palæontology of the Turbiferous beds is described, and the Shippea man found in them is shown to agree with the Bronze Age men found in the round barrows.

6. Palæontology in California.—A series of five papers issued within two months bears witness to the activity of the great school of palæontology which Professor J. C. Merriam has built up in the University of California.

7. Parapavo californicus.[3]—Dr. Miller, in the light of much more abundant material, reviews the interesting bird from Rancho la Brea which he formerly described as a peacock. The new investigation suggests that it is in many respects intermediate between the peacock and the turkey, and it is hence referred to the new genus *Parapavo*.

8. In another paper Miller[4] describes two vultures from the Rancho la Brea asphalt-pits, both new genera.

9. Professor Merriam[5] describes very fragmentary material from the Etchegoin as *Pliohippus proversus*. This horse, which is near '*Equus*' *simplicidens* from the Texan Pliocene, seems to provide an intermediate stage between the typical *Pliohippi* and such primitive horses as *Equus stenonis*.

10. American Bisons.[6]—The paper contains a detailed discussion, with many measurements, of a fine series of skulls and jaws of *Bison*

[1] A. W. Rogers, "The Occurrence of Dinosaurs in Bushmanland." S. H. Haughton, "On some Dinosaur Remains from Bushmanland": Trans. Roy. Soc. S. Africa, vol. v, pt. iii, pp. 259–72.

[2] *Notes on the Fenland*, by T. McKenny Hughes; with "A Description of the Shippea Man", by A. Macalister. Cambridge, University Press, 1916, 6*d*.

[3] L. H. Miller, "A Review of the species *Pavo californicus*": Univ. Cal. Bull. Dept. Geol., vol. ix, No. vii, pp. 89–92.

[4] L. H. Miller, "Two Vulturid Raptors from the Pleistocene of Rancho la Brea": op. cit., No. ix, pp. 105–9.

[5] J. C. Merriam, "Relationship of *Equus* to *Pliohippus* suggested by Characters of a New Species from the Pliocene of California": op. cit., No. xviii, pp. 525–34.

[6] A. C. Chandler, "A Study of the Skull and Dentition of *Bison antiquus*, Leidy, with special reference to material from the Pacific Coast": op. cit., No. xi, pp. 121–35.

antiquus, an extinct Pleistocene Bison, found throughout the United States, which differs from the living American Bisons with larger horn-cores and differing markedly in their angle of insertion.

11. Californian Pliocene.[1]—The paper is a valuable contribution to the later Tertiary stratigraphy of California, containing as it does descriptions of many sections with very full faunal lists, which are carefully analysed, the percentage of species restricted to a given formation and those ranging through into others being well brought out.

12. Miocene Vertebrates from Nevada.[2]—In this paper Professor Merriam describes an important but unfortunately fragmentary fauna of Upper Miocene age from West Nevada, and compares it with other groups of mammals of similar age in the State. The most interesting types are *Hypohippus nevadensis*, a species with remarkably primitive milk molars representing a new sub-genus *Drynohippus*, and *Tetrabelodon* sp., an interesting Mastodon with a symphysis of a length intermediate between typical Tetrabelodons and ordinary Mastodons.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

May 10, 1916.—Dr. Alfred Harker, F.R.S., President in the Chair.

The following communications were read:—

1. "Carboniferous Fossils from Siam." By F. R. Cowper Reed, M.A., Sc.D., F.G.S.

The fossils described in this paper were collected by the Skeat Expedition from Cambridge in the year 1899, at a locality called Kuan Lin Soh, in the Patalung district of Lower Siam, and were briefly mentioned in the 'Reports' of the British Association for 1900 and 1901. They occur in a pale, fine-grained, jointed siliceous rock with an irregular or sub-conchoidal fracture. The field relations of the beds have not been recorded. The general facies of the small fauna which the available material has yielded indicates a Lower Carboniferous age for the beds, and the affinities of the species seem to be European and suggest the Culm Series. In 1913 Mr. J. B. Scrivenor, on the strength of the earlier determination of the fossils, referred the beds to his Raub Series of the Malay Peninsula, and the author draws attention to other Carboniferous beds in South-Eastern Asia.

2. "The Lurgecombe Mill Lamprophyre and its Inclusions." By Herbert Gladstone Smith, B.Sc., F.G.S.

A lamprophyre-dyke intrusive into Culm Shales has recently been exposed at Lurgecombe Mill, near Ashburton (South Devon). The rock is compact and fine-grained, small crystals of biotite

[1] Bruce Martin, "The Pliocene of Middle and Northern California": op. cit., No. xv, pp. 215–59.

[2] J. C. Merriam, "Tertiary Vertebrate Fauna from the Ada Mountain Region of Western Nevada": op. cit., No. xiii, pp. 161–98.

imparting to it a characteristic lamprophyric appearance; vesicles with secondary minerals appear towards the margins.

In thin section, idiomorphic biotite, olivine pseudomorphs, and felspars are seen to make up the bulk of the rock; chlorite and secondary quartz occupy the interstices.

Analysis yields a small percentage of alkalies, the potash being slightly lower than the soda.

One of the thin sections was seen to contain crystals of blue corundum associated with magnetite, in a patch which was obviously foreign to the rock. With the object of obtaining additional examples, many slices were cut, sections being made of those that seemed promising. In this way several of these inclusions were obtained, the largest being about 0·3 inch in diameter. All contain corundum and magnetite, but in some cases staurolite also is present and more rarely green spinel. Further information concerning the corundum and staurolite was obtained by crushing the rock, and separating the constituents by means of heavy liquids. A well-formed crystal of the former mineral is tabular, large basal planes being combined with a subordinate rhombohedron, and it is probable that all the corundum of the rock is tabular in habit.

The corundum, staurolite, green spinel, and associated minerals probably owe their origin to a process of inclusion of fragments of the argillaceous country rock, and very definite borders of biotite surrounding some of the inclusions suggest that these are merely unassimilated remnants of larger fragments.

II.—Geological Society of Glasgow.

1. At a meeting of the Geological Society of Glasgow on April 13 Mr. Alex. McLean read "Notes on the Age of the Human Race based on Evidence found in Post-Pliocene Strata". He referred to the opinion held in certain quarters that the age of the human race was not many times greater than the sum of the classical and historical periods, and quoted many authorities to show that, so far from this being the case, the investigations carried out during the last half-century had produced evidence of a vastly greater antiquity. In the ancient river gravels and in caves and on other sites human relics had been found which gave clear evidence of a series of well-marked stages in the progress of the race from a state of extreme simplicity.

Mr. H. R. J. Conacher read "Notes on an Occurrence of Petrified Plant Remains in Lower Limestone Strata at Bridge of Weir". He said that in the strata immediately underlying the Blackhall Limestone in the banks of the Gryfe there was exposed a group of about half a dozen tree-stumps. These showed the well-known external characters of the roots of *Lepidodendron* and *Sigillaria*, and in addition parts of the internal woody tissue. The main axis showed that a kind of 'tap-root' had existed, and a series of slowly tapering ironstone cylinders, with calcite cores, which penetrate the embedding shale, no doubt represent the rootlets proceeding from the spreading roots. So far none of these rootlets have been found with any vestiges of internal structure preserved, but such may yet come to

light. Relics of aerial branches also occur, but these are in a state of preservation much less favourable for microscopic study. The tissues in the main roots where in the best condition have been preserved in calcareous material, which permits the employment of high powers of magnification, and the structures are undeformed by pressure, but the aerial stems are preserved in iron pyrites, the opaque crystals of which have quite obliterated the finer details. It would seem that the roots, embedded in the soft mud and readily accessible to the petrifying mineral solutions, had thus had their harder parts preserved from decay and enabled to resist the pressure exerted by the overlying deposits. The aerial branches, on the other hand, shaken from the dead trees were already much decayed and deformed by pressure before the mineral solutions had the opportunity to act. A series of specimens from the locality was exhibited, including microscope sections shown by the aid of the micro-projector.

III.—Liverpool Geological Society.

April 11, 1916.—J. H. Milton, Esq., F.G.S., F.L.S., President, in the Chair.

The following paper was read :—

"Notes on some Ferruginous Nodules in the Permo-Triassic Sandstones of South-West Lancashire." By T. A. Jones.

The author first described some small hard spheroidal concretions found last year during trench digging at Knowsley Park, presumably in Lower Soft Bunter Sandstone. They consisted of sand-grains embedded in a dark-brown cement of hydrated ferric oxide, which in volume was at least equal to the detrital material. The cores of the concretions were lighter in colour and less perfectly cemented than the outer shell. A striking feature was the large quantity of secondary silica present.

The so-called 'sulphur-balls' found in large numbers in colliery borings at Wigan and St. Helens in soft sandstone overlying the Coal-measures were then described. These consist of well-rounded grains of quartz and quartzite cemented by iron pyrites or marcasite. The most interesting and significant feature characterizing them is the presence of small knots of grains cemented by calcite. Tiny fragments of calcite also occur attached to the detrital grains, or lie isolated in the ferric sulphide. A gradual replacement of an earlier calcareous cement by ferric sulphide has therefore taken place, and this without disturbing the stratification of the sand-grains which is clearly visible across the nodules. A brief discussion of the origin of the iron cementing material in the sandstones followed.

CORRESPONDENCE.

THOUSAND FOOT PLATFORM IN ARRAN.

Sir,—Dr. F. Mort, in his paper on "Glacial Erosion in N. Arran" (abstract Trans. Geol. Soc. Glas., vol. xv, p. 415), calls attention to

a 'platform' at 1,000 feet above sea-level. In my paper on the Arran Granite (Trans. Geol. Soc. Glas., vol. x, p. 216) I notice the immense denudation that had taken place in Arran when the sea worked at 600 to 1,300 feet above present sea-level, and give sections. I also note the fact that all the glens (with one notable exception) occur in synclines of the granite slabs, and all the mountains have the slabs arranged as anticlines or quaquaversal dips (with one exception). I have also shown by a diagram that the slabs dip all round the granite area (which is nearly circular) at from 15° to 45° *towards* the slate, and give what I consider to be an explanation of these features. I also note the principal glacial phenomena, the thickness and quality of the Boulder Drift, moraines, etc., and how the drift had been carried *all round the granite area* on to the slate. I may say here that I saw no boulders foreign to the island on the granitic area, which is about 41 square miles. I do not, of course, suppose that all the immense denudation noted above took place during the Glacial Period—probably only a very small part of it. It is my firm opinion that the slate partly filled what are now the valleys at one time, and being more easily denuded than the granite this gave the original direction to the valleys or glens. In other papers I have shown that there is no Arran Granite in Ayrshire, except small bits along the shore which may have been brought as ballast.

J. Smith.

Dykes, Dalry, Ayrshire.
May 6, 1916.

OBITUARY.

LIEUT. R. L. VALENTINE,

7th Battalion Royal Dublin Fusiliers, Geologist on the Geological Survey of Ireland.

Born April 16, 1890. Died April 30, 1916.

Lieut. R. L. Valentine, of the 7th Battalion Royal Dublin Fusiliers, who died from wounds in France on April 30, 1916, was born on April 16, 1890, at Portora School, near Enniskillen, where his father was classical master. He was educated at the High School, Dublin, and gained a scholarship in the Royal College of Science for Ireland, receiving the Associateship of the College in 1912. He especially devoted himself to natural history and geology, and was engaged on a research in 1913–14 as to the horizon of the lowest Avonian strata at Hook Head, co. Wexford. He obtained by competition the post of Geologist on the Geological Survey of Ireland, and completed the Civil Service qualifying examination while in military training at the outbreak of the War. He gave high promise of becoming prominent amongst scientific men in Ireland, and his unfailing cheerfulness and readiness of resource endeared him to those who looked forward to working with him as a colleague.

G. A. J. C.

MISCELLANEOUS.

Geological Notes of Queensland.[1]

From the Gulf of Carpentaria to the Darling Downs, north to south, the fossil remains of extinct mammalia have been found in indurated muds, the beds of old watercourses. The bones and teeth are those of *Diprotodon Australis*, *Macropus titan*, *Thylacoleo*, *Phascolomys*, *Nototherium*, crocodile teeth, etc. The *Diprotodon* inhabited the Queensland valleys abundantly, and the *Crocodilus Australis* had a great range inland. The *Diprotodon* remains are found chiefly in the most permanent water-holes. No human bones, flint flakes, or any kind of native weapons have yet been discovered with the extinct mammalia of Queensland.

Desert sandstone is the most recent widely-spread stratified deposit developed in Queensland. Since it became dry land the denudation of this formation has been excessive, but there is still a large tract in situ. Probably this desert sandstone covered the whole of Australia at one time. (It is possible that desert sandstone in Queensland has value for free gold.) On the vast plains west of the dividing range Cretaceous strata are found; hot alkaline springs occur in these plains, and the discovery of these suggested the possibility of the existence of artesian water long before the bores were sunk from which flow "Queensland's rivers of gold".

The whole of Queensland is a vast cemetery of fossilized species—on the surface, buried in drifts, or hidden in clays. The plains of the Flinders River disclose great deposits of marine fossil shells—Belemnites and Ammonites and remains of extinct animals. In the Gulf of Carpentaria, 40 or 50 feet below the alluvial deposits forming the banks of rivers, firmly embedded in the hard cement—water-worn stones in an ironstone clay—are the bones of innumerable extinct gigantic animals that, far back in prehistoric ages, roamed over the Gulf country: *Diprotodon*, *Nototherium*, *Zygomaturus*, and *Thylacoleo*, grass-eaters and flesh-eaters. The utter extinction of these creatures can only be explained by a great change of climate and prolonged periods of drought. Gigantic alligators, turtles, and marsupials abounded in those days, suggesting a luxuriant and abundant vegetation, both trees and herbage.

From an economic point of view one may say that three-fourths of the area of Queensland forms good pastoral land. Of this 60,000 square miles contain valuable mines of gold, with outcrops of copper and lead ores, as well as rich deposits of tin; 24,000 square miles are capable of producing illimitable supplies of iron and coal. It may be safely asserted that in Queensland is a wealth of material resource comparing favourably with any other part of Australia.

[1] From the London Correspondent of the *North Queensland Register*, 22 Basinghall Street, London, E.C.